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NOTES
ON
DRAINAGE

Dup

NOTES ON DRAINAGE

Class Room, Field, and Laboratory Exercises for Students of Land Drainage

BY

E. R. JONES

Instructor in Soils and Drainage at the University of Wisconsin

ILLUSTRATED

FIRST EDITION

PUBLISHED BY THE AUTHOR
Madison, Wisconsin

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Democrat Printing Company, Madison.

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PREFACE

The aim in the pages that follow has been to present to the student a brief but systematic outline of the work which hitherto has been given to students of drainage at this college. Farmers' Bulletin, No. 187, by Mr. C. G. Elliott, drainage expert for the U. S. Department of Agriculture, and Bulletins 138 and 146 of this station by Prof. A. R. Whitson and the author, will be used by the student as collateral texts. For this reason, care has been taken not to duplicate except in a very general way, the material presented in these bulletins. The effort has rather been merely to adapt them to the needs of the student and to supplement them with a more thorough study of the conditions that require drainage, of the methods that are employed, and of the surveying operations that bear upon drainage practice.

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Much credit is due to Prof. Whitson for helpful suggestions on the arrangement of material. Acknowledgments are also due to W. & L. E. Gurley, instrument makers of Troy, N. Y., for their courtesy in loaning the cuts of surveying instruments.

E. R. J.

University of Wisconsin,
College of Agriculture,
January, 1908.

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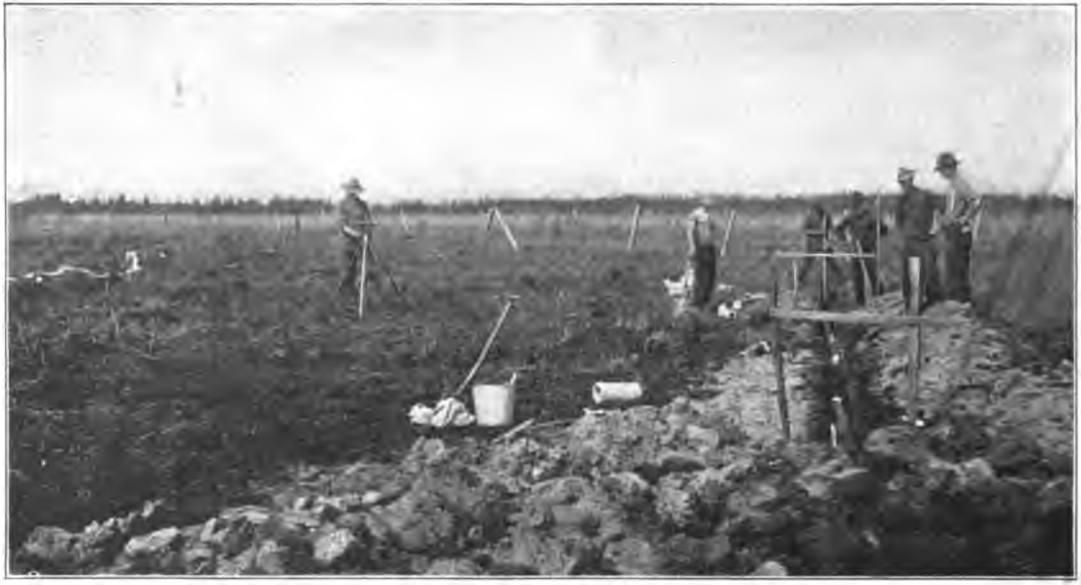


THE REAL THING.

The grade lath in the foreground marks the point at which the line of tile curves to the left to intercept the seepage from the upland. Depth at the head had to be sacrificed to obtain the scanty fall of 0.1:100. The tile are nearly four feet deep at the outlet, but were laid "against the slope." The trench here is 700 feet from the outlet, and is scarcely more than two feet deep. At the extreme left the tile have been hauled for the next lateral.

Part One.

NOTES ON SURVEYING.

CHAPTER I.

INTRODUCTION.

1. Casual Observations.—Every farmer's son, to be sure, has learned to measure long distances by counting *forty-lines;* he is familiar with the jogs in the fences along correction lines, if there is one in his locality; he knows that this *forty* is the S. E. ¼ S. W. ¼, Sec. 3, and that another is the N. E. ¼ N. W. ¼, Sec. 10, and if he has seen his father's tax receipts he knows perhaps that both are in Township 16, Range 5 West; he has seen the corner-stones every half mile on section lines, but he has never seen one at the center of a section; and he has heard too, that the forties on the west line of a township are apt to be more or less than the normal size. None of these facts are new to him. Neither are they altogether new to any of us. Nevertheless, it seems advisable to review, in this connection, some of the elementary details of surveying.

2. Surveying and Land Drainage.—Surveying has been called the art of making such field observations and measurements as are necessary to determine positions, areas, volumes or movements on the earth's surface. A study of the surveying operations involved naturally precedes one of the principles of artificial land drainage because no work of man is practiced with more rigid conformance to conditions found on the earth's surface, than is land drainage.

Drainage is vitally concerned with the difference in elevation between points on the area in question. The distance through which this fall is to be distributed is another factor. Then too, the extent of the area to be drained must be considered. This is the first step in the reclamation of broad expanses of marsh lands, untouched perhaps by all save the original survey, according to which the sub-division was made. Old section-corners must be located so that correct descriptions can be obtained, of all parcels of land to be included in the proposed drainage district.

3. **Surveying Versus Engineering.**—The distinction between surveying and engineering is a definite one although the two terms are commonly used inter-changeably. A surveyor is one who makes observations and collects and records data in the field. The engineer interprets these data and applies the conclusions he bases thereon to the proposed structure. A surveyor need have no knowledge of engineering, but it is essential that the engineer have a sufficient knowledge of surveying to enable him to understand the data given him by the surveyor.

4. **The Probability of Errors.**—No physical measurements are absolutely accurate. This is especially true with the observations made in surveying. It would be remarkable indeed if two measurements of a line 500

feet long checked to the thousandth of a foot. In fact it would give rise to a suspicion that the work was unreliable. There will invariably be a slight difference between any two measurements. The judgment of the surveyor should dictate to him the limit of permissible error. His standard should change with the nature of the work he is doing. He would be foolish indeed who would measure the length of a proposed lateral with as much care as he would measure a baseline for a plane-table map. It would be useless to read a rod to hundredths when held upon ground so rough that the rod held half an inch one way or the other would be nearly a tenth of a foot lower. And it would be far from consistent to read a rod to thousandths on long sights where the non-adjustment of the instrument gives an error of a number of hundredths.

5. Cumulative and Compensating Errors.—One should learn to recognize the character of the errors. They are either *cumulative* or *compensating.* A cumulative error is one which always occurs in the same direction, as an error caused by a permanent kink in a chain. A compensating error is one occurring now in one direction and now in another. A man setting chaining pins is as apt to set one a little too far back as he is to set another too far ahead. Where the errors in one direction compensate for those in the other, the final result is unaffected.

The accuracy of all surveying work is checked by a second measurement. If the discrepancy is thought to be too great, a third measurement will usually show which of the two former ones was the more nearly correct. Where averages of two or more careful readings are taken, the error is brought within the limit of reason and for all practical purposes is eliminated.

6. Recapitulation.—Surveying, then, is the essential auxiliary of land drainage. It involves the use and care of instruments. A survey should be conducted with the use of methods that will be conducive to both reasonable accuracy and economy. And finally, it is not complete until all observations of value are recorded in a neat intelligible form in a field book or upon a map.

CHAPTER II.

LINEAR MEASUREMENTS.

The most elementary operation in surveying is that of measuring the length of lines. It is accomplished by the use of a chain, a tape or a rod. Rods like the stone-mason's ten-foot pole are used for measuring short distances only, and will not be considered here.

7. The Chain.—The engineer's chain is made of wire links one foot long, including the connecting links. It may be either 50 or 100 feet long and should be made of wire heavy enough to stand a reasonable amount of pulling without bending.

Gunter's chain is similarly made except that it contains 100 links, each 7.92 inches long and aggregating 66 feet or four rods. It takes its name from its inventor, an English astronomer who lived about 1620. It is used still in all U. S. land surveys, the term *chain* always meaning a Gunter chain. Its advantage lies in the ease with which square chains may be reduced to acres, ten square chains equalling one acre.

The most serious disadvantage of the chain is its tendency to stretch by wearing. For every link there are two or four surfaces subject to wearing and 100-foot chains have been known to stretch 0.4 feet in chaining a line 300 miles long.

8. The Steel Ribbon.—Steel ribbons are not subject to stretching by wearing. They are of varying thicknesses, hence vary in flexibility and are from an eighth to a quarter of an inch wide. They are made in all lengths up to 500 feet and contain marks every ten feet. For ten feet at each end, each foot is marked, and the last foot on each end is marked to tenths and hundredths of feet.

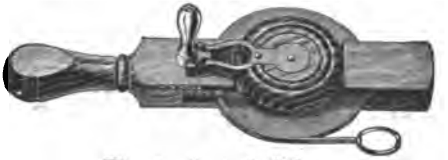


Fig. 1.—A steel ribbon.

9. Metallic Tapes.—Cloth tapes reinforced with fine copper wires woven into the cloth are called ***metallic tapes.*** They are wide enough that the marks and figures may be seen much more easily than those on a steel ribbon. Metallic tapes, however, are apt to stretch with use.

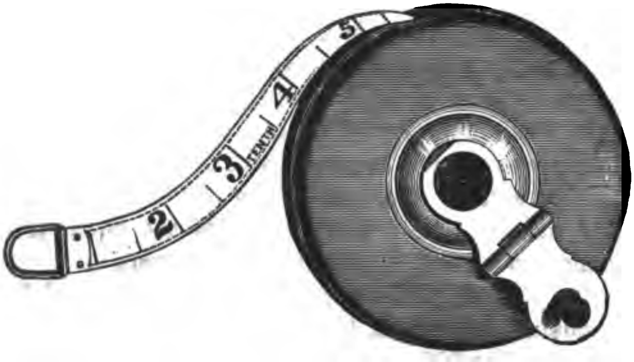


Fig. 2.—A metallic tape.

10. Standardizing a Chain.—Steel ribbons, then, are the most accurate instruments of measurement. Chains and metallic tapes may be standardized by being pulled taut at the side of a steel ribbon, or between two fixed points, whose distance apart has been measured by a steel ribbon. The corrected mark may be put at the proper place, or the error in length may be just noted at the time, and correction made later upon the distance measured.

11. Comparative Merits.—Considered separately and in detail, the respective merits of chains and tapes would be:

Chains:
- Advantages:
    1. They do not break.
- Disadvantages:
    1. They stretch by wearing.
    2. They are heavy.
    3. Links may become permanently distorted.
    4. Links may double back or kink.
    5. They are not finely graduated.

Metallic Tapes:
- Advantages:
    1. They can be read easily.
- Disadvantages:
    1. They stretch with pulling.
    2. They wear out quickly.

Steel Ribbons:
- Advantages:
    1. They stretch but little with pulling.
    2. They do not wear.
    3. They do not become distorted.

4. They are light and convenient.
5. They are finely graduated.

Disadvantages:

1. They break when they kink.
2. The marks and figures are hard to see.

Except for the relative merits just noted it makes no difference whether a chain, a metallic tape or a steel ribbon is used, and in this and subsequent chapters the term *chain* will be used to designate any instrument used for measuring. Likewise the art of measuring horizontal distances on the earth's surface will be called *chaining*.

12. Alignment.—Imagine a vertical line dropped to the two points whose distance apart is sought. It is the horizontal line connecting these two vertical lines that is to be measured. The chain must be made to coincide with, or be parallel to, this line. The process of placing the chain in such a position is known as *alignment* and it must be accomplished in both the horizontal and in the vertical planes. Since the straight line thus obtained is the shortest distance between the two points, any error in alignment will tend to make the measured line longer than the line that should have been measured.

13. The See-Saw Method.—Line rods must be put at each end of the line in question. This is to facilitate alignment in the vertical plane. Where the two ends are mutually invisible, the *see-saw* method must be employed. Each of the two chainmen stands with a line-rod as nearly as possible on line, one on each side of the obstructing object and as near to his end of the line as he can be and still see the other end. Each successively lines the other in, until, by a series of approximations, a straight line is staked out.

14. Horizontal Alignment.—On level ground, alignment in the horizontal plane may be accomplished by allowing the chain to rest upon the ground. On slopes, one end of the chain must be held in the air, and the point is projected to the ground by means of the plumb-bob. In such cases it is easy to hold the end of the tape too high or too low. A third man standing a rod or two on one side of the line can aid materially in securing a horizontal position for the tape. Comparison with horizontal lines on buildings that happen to be near will also serve to assist in the operation. Where the slope makes it necessary to hold the chain more than five feet in the air, when the entire length of the chain is used, only a portion of the length should be used at a time. This is known as *breaking chain.*

15. Classification of Errors.—The probable errors in chaining classified according to their character are as follows:

Cumulative:

1. Imperfect alignment.
2. Imperfect condition of the chain.

Compensating:

1. Degree of tautness.
2. Setting the pin.
3. The swinging of the plumb-bob.

16. The Method in Detail.—In chaining a line it will be found advantageous to adhere most rigidly to the following directions:

With the zero mark on the chain to the rear and on *the initial point, the chain is unwound in the direction of the line-rod at the other end of the line to be measured. Keeping his body out of the line of sight, holding a pin vertically at the desired point on the chain with one hand, and holding the chain taut with the other, the head chainman moves the chain and pin as directed by rear chainman until he gets the pin on the line of sight. The rear chainman then calls out "line" and centers his attenton on the zero mark and the initial point. This done, he calls out "stick" and the head chainman, holding the chain taut and on line, slides the pin along the tape until the intersection of its forward surface with the ground, marks the desired point, whereupon the pin is stuck, at a backward slant of about 45°. He then reads the chain once more and calls out "stuck" to the rear chainman, who pulls up his pin and comes forward. They proceed from this station, as from initial point.*

17. Tallying.—In chaining long lines it is convenient to have eleven chaining pins. One is left at the beginning of the line and the head chainman leaves one at each succeeding station along the line. When he has put in his last pin, ten stations have been chained, each representing the length of the tape. Ten chains are called a *tally,* and with a 100-foot tape this is 1,000 feet. The rear-chainman has picked up the pin at each station as he left it, and he hands them—ten in all—to the head chainman. When these have all been used, another tally has been chained. Each time it is necessary to break chain, the rear chainman hands the head chainman a pin.

If this method of tallying is used, none but the final results and a few remarks need be recorded in the field book. In the absence of this method the following form of notes will simplify matters somewhat:

TABLE I.

A form in which chaining notes may be kept.

From.	To	Distance	Total distance.	Error.	Remarks.
A	1	50	50	....	Problem I.
1	2	50	100	....	To chain the line AB.
2	3	25	125	....	Party:
3	4	50	175	....	Roberts, head chainman.
4	B	33.4	208.4	....	Williams, rear chainman.
B	1	40	40	....	Date:
1	2	50	90	....	June 8, 1907.
2	3	25	115	....	Weather:
3	4	50	165	....	Rather windy.
4	A	43.6	208.6	0.2	Instrument:
					50-foot metallic tape No. III.
		Average	208.5		Condition of chain:
					0.13 feet too long.
					208.5x1.0026=209.04 real length.

Both chainmen should record the above notes. As soon as a line is chained it should be re-chained back to the starting point for a check.

18. Pacing Distances.—Where none but approximate distances are desired, satisfactory results may be obtained by pacing. With practice, a man should be able to pace distances with an error not greater than three per cent of the total. The method is rapid and convenient. If, for example, there are two fences a few rods apart, and near to where a forty-line may be expected, it is probable that one of the fences is on the forty-line. Which one, may not be known to the man unfamiliar with the ground. However, the distance from a known forty-line may be paced accurately enough that it will be easy to see which of the fences is on the line in question.

19. The Stadia Method.—There is another rapid method of measurement that is more accurate than pacing. Some telescopic instruments are provided with two parallel, horizontal cross-hairs or wires across the field of vision. These wires are called *stadia wires* and are usually of such a distance apart that when a rod is held 100 feet away, one foot of the rod is visible between them. As the rod is taken farther away from the instrument, the amount of the rod visible between the stadia wires will be directly proportional to the distance of the rod except for a slight variation in visual angles of the lens. At 500 feet, approximately five feet of the rod will be included between the wires. Where the feet on the rod are graduated to tenths, distances may be read to ten feet.

If the telescope tube is not horizontal, it must be remembered that the distance measured is the hypothenuse of a right triangle, one of whose angles is the angle formed by the telescope with the horizontal. The horizontal distance of the point on which the rod is held is the base of the right triangle and its perpendicular represents the elevation of the point above the base. Where the angle of the telescope tube can be measured, both of these distances may be computed. The hypothenuse multiplied by the sine of the angle gives the perpendicular and multiplied by the cosine gives the base or the horizontal line, approximately in each case.

20. The Random Line.—There is a scheme based on the same principle as stadia measurements, for the measurement of a line and for the location of points thereon, when the two ends are mutually invisible, and so far distant that it is not expedient to set line rods by the see-saw method. A ***random-line*** is taken approximately in the right direction, and pursued until a point is reached to which a perpendicular may be dropped from the end of the line whose length was primarily sought, and which may now be computed since it is the hypothenuse of a right-triangle whose base is the random line and whose perpendicular can be measured. Intermediate points, as section corners (**33**), may be located by taking set-offs from the random line which will be directly proportional to the distance from the starting point.

CHAPTER III.

ANGULAR MEASUREMENTS.

21. By Means of the Chain.—The most familiar scheme for angular measurement is perhaps that for the right angle, known as the ***three, four and five*** method. Suppose that a perpendicular to the line AB is desired at A. Measure off AC four feet long and lying in AB. Then find the point D, such that its distance from A will be three feet, and from C will be five feet. The line AD is the required perpendicular. The distances taken may be any multiples of three, four and five as 30, 40 and 50, and preferably so, because of the greater accuracy with which the line may be extended past D.

By means of a trigonometric formula any angle may be measured with nothing more at hand than an ordinary chain, as follows: Set a stake on each of the two lines forming the angle x, and equidistant from their intersection. Call this distance b. Measure the distance between the two stakes and call it a. Then by supplying numerical values for a and b in the equation given in the appendix and by using a sine table, the value of x may be found. This is a clumsy method to be sure, and we have instruments that are both more convenient and more accurate.

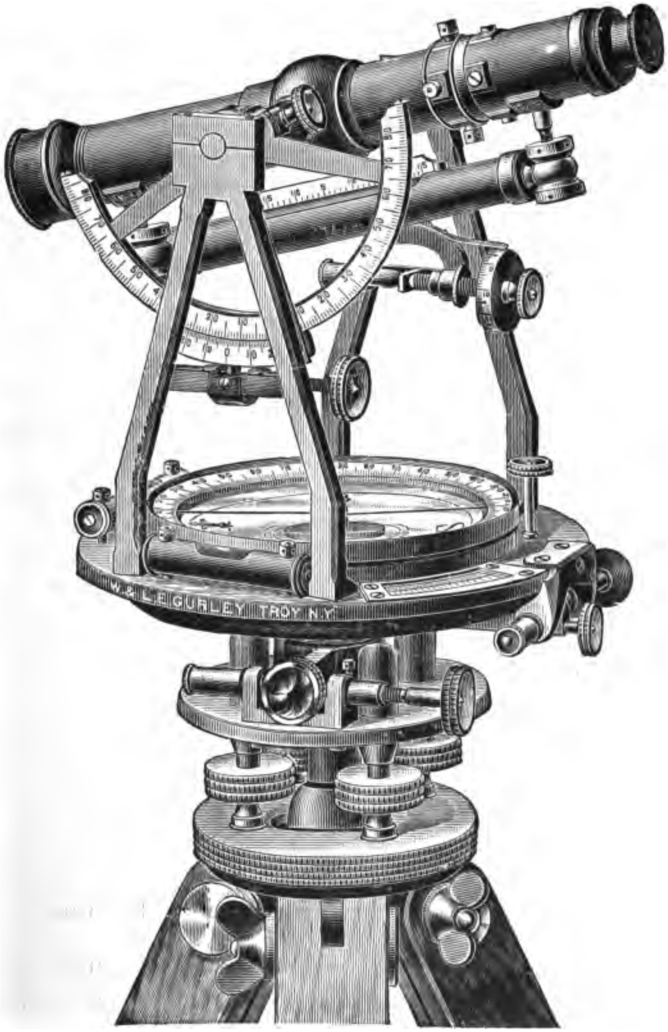


Fig. 8.—An engineer's transit. The movement of the telescope tube in a vertical plane makes possible the measurement of angles on hilly ground. On level ground the horizontal circle of the level may be used.

22. Instruments of Greater Accuracy.—The instrument most commonly used is the *transit.* It consists of four essential parts: (1) A line of sight; (2) a graduated circle or limb; (3) facilities for holding the limb firmly, and approximately level; and (4) a vernier scale free to move with the line of sight, and in such close contact with the limb that the reading will be easy and accurate. Some *engineer's levels* are provided with a horizontal circle and a vernier scale for measuring angles, but their use is confined to comparatively level ground, and when so used are performing the functions of a transit. Telescopic lines of sight are marked by the intersection of the horizontal and vertical cross wires.

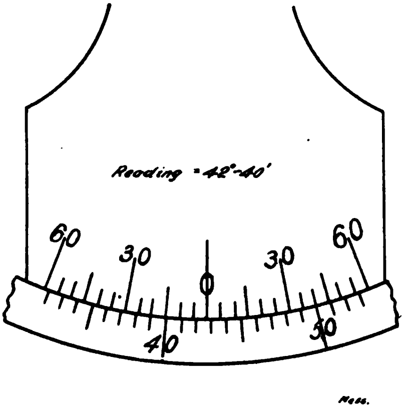


Fig. 4.—A simple vernier scale for reading the graduated circle.

23. The Vernier Scale.—Since all depends upon the reading of the limb taken by means of the vernier scale, a careful study of the latter is of prime importance. In Fig. 4 the outer circle is the limb and the inner the vernier scale. It will be noticed that twelve graduations on the vernier equal eleven of those on the limb. Starting from any given point, each successive mark on the vernier will fall short of its corresponding mark on the limb, by one twelfth of the distance between the latter marks, a distance which in this particular case equals one degree, and one twelfth of which equals five minutes. In all cases it is the zero of the vernier which indicates the point on the limb to be read. In Fig. 4, this mark is a certain distance past 42°, and as many five-minute intervals past it as there are marks on the vernier before one of those on the limb has "caught up" with its corresponding mark on the vernier. It is evident in this case that it is on the eighth mark past the zero that the coincidence takes place, and hence the reading is 42° 40′. Some instruments are so finely graduated that it is possible to read to minutes, instead of to the nearest five-minute mark.

24. The Necessary Readings.—To measure an angle, the instrument is set up with its axis of revolution over the vertex of the angle. The line of sight is made to take the direction of one of the sides. Some instruments are provided with a *tangent-screw* to make the coincidence more accurate. When this has been accomplished, the reading of the limb is taken and recorded. The line of sight is then revolved until it coincides with the other line forming the angle. In the meantime the limb has remained stationary, so the difference between the two readings taken on the two lines respectively is the magnitude of the angle. This is the underlying principle of all angular measurements by means of a line of sight.

25. The Azimuth.—To simplify the designation of the direction of lines, a line running from north *to* south has been taken as a standard or datum direction. All other lines are designated on the basis of the angular magnitude traversed by them when revolved in a clock-wise direction from the datum or *south* line. The angle thus traversed is called the ***azimuth*** of the line. The azimuth of an *east* line is then 270°, and that of a *west* line is only 90°. From this it is evident that a line is always taken as extending from the point at which it is observed, and since the observation may be made from either end, every line has two azimuths. The *forward azimuth* of a line is its angular deviation from the south point when measured at a rear station forward along the line. The ***back azimuth*** is its angular deviation from the south point at a forward station when measured back along the line. The two azimuths of a line differ by 180°.

Where a line of a given azimuth is to be laid out from a given point, it is often necessary to run from a known azimuth, a *traverse*, which is a series of consecutive lines whose azimuths are determined as progress is made.

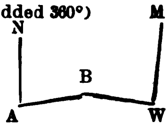
26. How to run a Traverse.—Suppose, in the accompanying figure, an azimuth of 180° is desired. The known azimuth WM is 187° 54′, extending from a point on the east porch of Washburn Observatory to the dome of Mendota Hospital. The instrument is set up at W and the point M is observed. The reading is 154° 46′. The point A is invisible from W, so the point B is established and observed, and the reading 67° 6′ is taken. The angle MWB is thus 87° 40′. Since it lies on the left of the known azimuth, this angle must be subtracted from 187° 54′, to find the azimuth of WB, which is then 100° 14′. The instrument is then set up at B, the point W observed and the azimuth of BA is found from the angle it forms with BW, the back azimuth of which is 100° 14′ plus 180° or 280° 14′.

The point A has been finally reached, and an observation is made of B. The difference between the back azimuth of AB and 180° is the angle which must be set off to the left to secure a line of sight extending due north.

Whenever the zero of the vernier moves past the zero on the limb, 360° must be added to the smaller reading, before the subtraction to find the angle is made. The accompanying form shows how the notes for a traverse are kept. It will be noticed that the first entries are made at the bottom of the page. The right-hand page should always contain a sketch of the traverse.

TABLE II.

The form in which traverse notes should be kept.

Station occupied	Station sighted.	Reading.	Angle.	Azimuth.	Remarks.
		° ′	° ′	° ′	
A......	N	53 19	83 8	180	BAN { Transitman, Davis Rodman, Roberts. Date: Jan. 2, 1908.
A........	B	136 27	....	263 8	
B........	A	145 20	162 54	83 8	WBA (added 360°)
B........	W	342 26	....	280 14	
W........	B	67 6	87 40	100 14	MWB 
W......	M	154 46	....	187 54	

27. The Compass.—Another method of laying out lines of a given azimuth is by means of the magnetic needle which is the distinguishing feature of a *compass*. The weakness of this method lies in the variations to which the needle is subject. Chief among these is its variation from the true north, which is known as its *declination*. A line along which there is no declination is an *agonic line*. This line passes through the United States northward from Charleston, S. C. At Madison, Wis., the declination is about 5° east of north, and it becomes greater with distance to the westward.

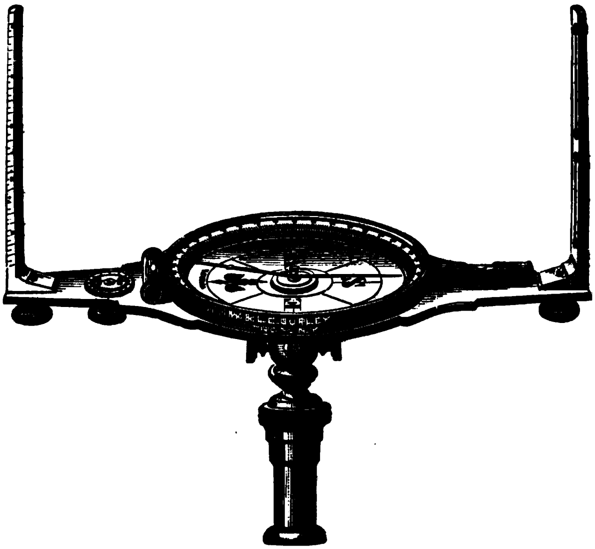


Fig. 5.—The engineer's compass. For work requiring extreme accuracy, this instrument can not be used.

When the azimuth of a line is found by means of the magnetic needle, it is called the *bearing* of the line. All lines have a *magnetic bearing*, indicated by the needle, and a *true bearing*, which is found by correcting the magnetic bearing for its error due to the declination of the needle. Bearings are designated with reference to their angular deviation from either the north or the south points of the compass, whichever is nearest. It is evident that no angle thus formed will be greater than 90°. An azimuth of 195° 30′ would be designated as North 15° 30′ East. Keeping these things in mind, then, it should be clear that the following relations exist between the different methods by which directions may be designated, where the magnetic declination is 5° East:

TABLE III.

Different methods of designating directions.

Line.	Magnetic bearing.	True bearing.	True bearing (back.)	Forward azimuth.	Back azimuth.	Angle.
	° ′	° ′	° ′	° ′	° ′	° ′
AB.....	N 25 30 E	N 30 30 E	S 30 30 W	210 30	30 30	
AC	N 87 20 E	S 87 40 E	N 87 40 W	272 20	92 20	(BAC) 61 30
CD	S 42 45 W	S 47 45 W	N 47 45 E	47 45	227 45	(ACD) 44 35
DE ..	N 46 25 W	N 41 25 W	S 41 25 E	138 35	318 35	(CDE) 89 10
EF	S 85 W	W	E	90	270	(DEF) 131 25

28. Practical Application.—The details of angular measurement have been dealt with in this connection because of their direct bearing upon a number of features of land drainage. It is true that ordinarily it makes no difference whether a line of tile runs due north or a degree or two east of north. This is not true, however, in the case of an open ditch, or a long line of tile in a drainage district, whose course for miles is designated in official papers by its bearing or azimuth. Then, too, this subject is discussed here because of its fundamental relation to the sub-division and mapping of land, topics that will be considered in subsequent chapters.

CHAPTER IV.

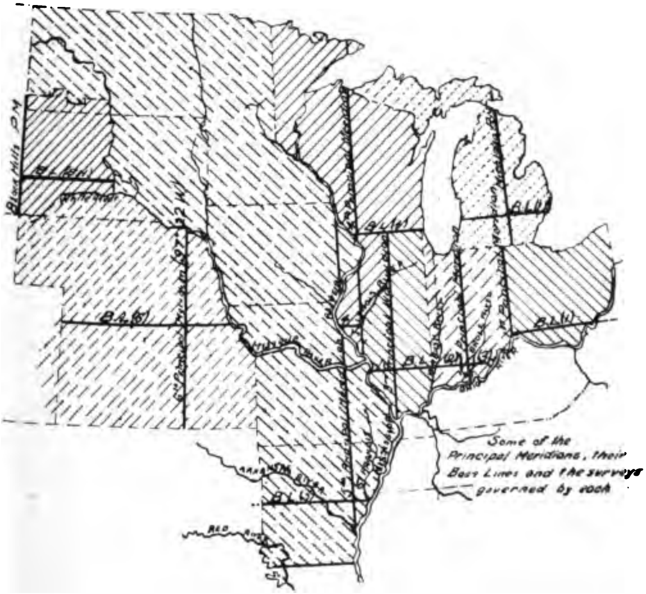
THE SUB-DIVISION OF LAND.

29. Units of Area.—In all English speaking nations the *acre* is the unit of land measure. It formerly meant an open field of any area but in the time of Henry VIII it was given a specific size. The Scotch acre differs from it in containing 6104 instead of 4840 square yards. In continental Europe the hectare is the standard. It contains 10,000 square meters and is sub-divided into 100 ares. It is equivalent to 2.47 acres.

30. Early Methods of Sub-division.—In the thirteen original colonies parcels of land are very irregular in outline, as a glance at a New England county map will show. County lines, town lines, and farm lines, follow no general direction. They do not run straight for any great distance but are made up of a series of kinks and curves, found also in parts of Texas where the Spaniards were the first to sub-divide the land.

31. The Present Method.—The confusion that is bound to result from such irregular boundaries, early showed the need of a more simple, uniform system of sub-division, and in 1787 Gen. Putnam devised such a system to be employed in the Ohio Territory. He created what has been named the *congressional township* containing 36 square miles or *sections* of 640 acres each. Another thing he created was a *base-line* and a *principal meridian,* the former being a parallel and latter a meridian, and hence each perpendicular to the other at their intersection.

32. Base Lines and Principal Meridians.—There are now twenty-four principal meridians and their accompanying base lines in use in different parts of the United States. Those governing the surveys of the upper Mississippi Valley and of Michigan are shown on the map in Fig. 6. The adoption of a base line and principal meridian is the first step in making an original survey.



Some of the Principal Meridians, their Base Lines and the surveys governed by each

Fig. 6.—Base lines and principal meridians. The surveys governed by each are shown by the adjacent shading.

33. Standard Parallels and Guide Meridians.—The next step is to run *standard parallels* and *guide meridians* every 24 miles from the initial point, which divide the land into *blocks*. Monuments are left every mile along the line as indicated by the heavy circular dots in Fig. 7. The half-mile points are also marked. A special kind of monument is left every six miles, at the

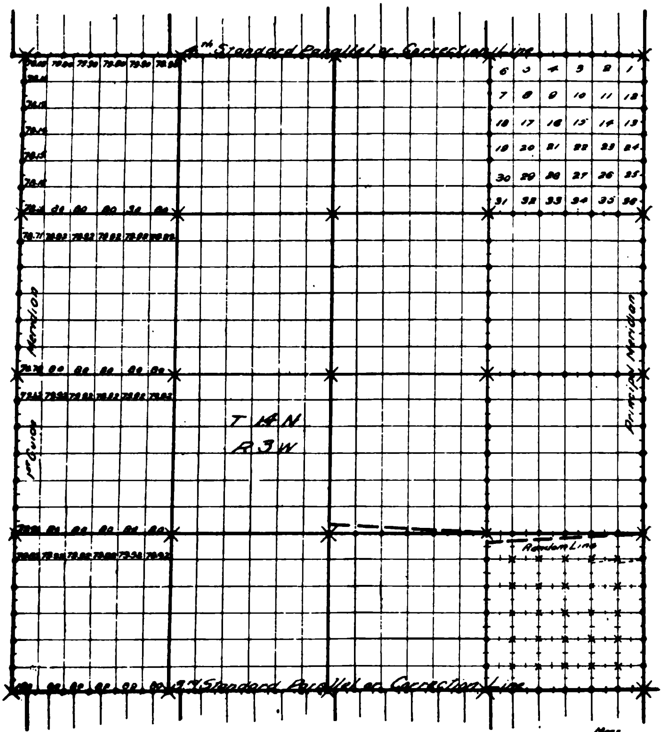


Fig. 7.—The rectangular sub-division of land. The convergence of the meridians is shown at an enlarged scale to facilitate the explanation.

township corners. *Range-lines* are then run due north from the three intermediate township corners on the base line. The mile-stones and half-mile points on all of these lines are put in, but for simplicity, are indicated on only the first range line in Fig. 7. This is done also on the *township-lines* which are finally located from random lines from one township corner to the next one due west. The latter will curve slightly on account of the convergence of the meridans. These lines must be run with great care. The magnetic needle can not be relied upon because of its variations. Only those instruments should be used that are provided with solar attachments, which make it possible to obtain bearings from the sun when its declination for the given day and hour are known.

34. Locating Section Corners.—All is done now but locating the corners of the interior sections of a township, and here the convergence of the meridians, already mentioned, introduces a complication. The section-lines are run due north from the section-corners on the base line, but at the end of five miles the distance between two section-lines at 40° of Latitude will be only 79.92 chains, while the corresponding section corners a mile farther north have already been located 80 chains apart. To prevent a jog, the line is run straight from the fifth section corner from the south line of a township, irrespective of direction, to the corresponding section corner in the next township. This is repeated in the second and third townships from the standard parallel, but the north line of the fourth township is always a correction line, and the jog is too large to make it expedient to try to avoid it, so the section lines are run due north to the correction line irrespective of the location of the section corners in the next township, as the lengths, 79.90 chains, will show.

35. The Quarter-Section Corners.—Monuments should be left every half mile along these section lines also. By setting the instrument at, or by measuring in a random line west from the north-east corner of each section, the half mile points on the east and west section lines may be found. The dotted random lines on the north sides of sections 11 and 12, T. 13 N., R. 1 W., illustrate the method. These half mile points mark the quarter-section corners. This is the extent of subdividing done by the government. The forty lines, or sixteenth lines as they are called, are run in by the land-owner.

36. The Monuments Used.—In some localities the government has provided dressed stones for monuments, but usually a stake with a hole dug in the ground in line on each side of it and about four feet distant is the extent of the marking done. The stakes soon rot or are destroyed and nothing but the holes remain to indicate the spot. Since but one line runs through the half mile points, only two holes are found, and such quarter-section corners are commonly called "two-hole" corners. Section corners are called "four-hole" corners. Section corners along correction lines are known as "three-hole" corners because the section lines run only to, and do not cross, the correction line. The half-mile points in the correction line are not marked for the row of sections on the south side of that line, and common parlance designates them and the interior corner in every section, as "no-hole" corners.

37. Quarter Sections of Abnormal Size.—Nothing as yet has been said of the discrepancy in area that will result from the convergence of the meridians. It will be noted that all measurements have been made from east to west. The error is continually crowded westward and finally lands in the west row of half sections in the township. The discrepancy will increase with the distance from the base line. Fig. 7 shows that the meridians six miles apart at the base, are 2.42 chains or about 160 feet nearer together when the next standard parallel has been reached.

It frequently happens that the quarter sections along the west line of a township contain more than 160 acres. It is simply the case of a rule working both ways, and where an error is made by the surveyors in running the guide meridians—something which is very often done—the west row of half sections are given the additional area that comes from that source. Nevertheless the convergence of the meridians makes the additional area smaller than it otherwise would be. This should make plain the reason why all deeds of conveyance contain the number of acres qualified by the phrase "more or less according to government survey." It is the original government survey that is binding in case of any legal contest.

38. How Townships are Designated.—In the foregoing discussion the term *base-line* has been used, when in Fig. 7 the Third Standard Parallel was meant. This is permissible because each standard parallel is virtually a base line for the four townships north of it. The same relation exists between the guide meridians and the principal one. Where the standard parallels and guide meridians are numbered, the description of a township as T. 14 N., R. 3 W. may be seen at a glance.

39. The Numbering of Sections—Fractions of Sections.—The numbering of the sections is shown in T. 16 N, R. 1 W.

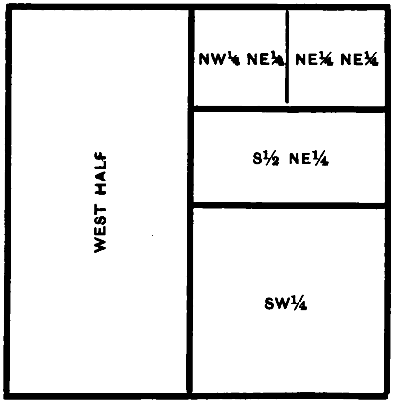


Fig. 8.—The several fractional portions of a section are designated in official papers as here indicated.

In conveyancing, and all other legal processes, portions of sections are described as indicated in Fig. 8.

CHAPTER V.

METHODS OF MAPPING.

The ordinary *map* is a diagramatic representation of the direction and length of lines on the earth's surface. **The ratio between the length of a line on the map to that of the line in the field which it represents is known** as the *scale.* The scale and an arrow indicating the north point of the compass should be included in the *legend,* or explanation accompanying the map.

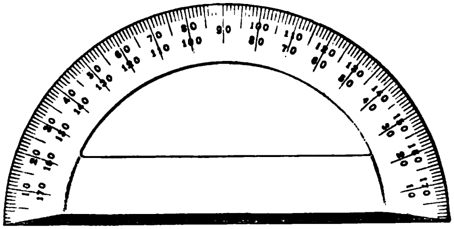


Fig. 9.—The protractor. An instrument used for copying anges.

40. Rectangular Areas.—The easiest field to map is a rectangular one. This is facilitated still farther by the use of paper containing squares. Letting each square equal four rods a field 40 rods by 80 rods could be represented in proper proportions by a map 10 squares wide and 20 long. Interior points could be located by measuring their perpendicular distances from two sides of the field at right angles to each other.

41. Irregular Fields.—We must remember however that all fields are not rectangular in outline. Some are cut by winding streams or irregular fences. It is true that the angles and distances may be measured by any of the methods which have been mentioned in previous chapters. These lines may be reduced to the scale of the map. A metal semi-circle graduated to degrees and called a *protractor* will aid in transferring the angles to the map.

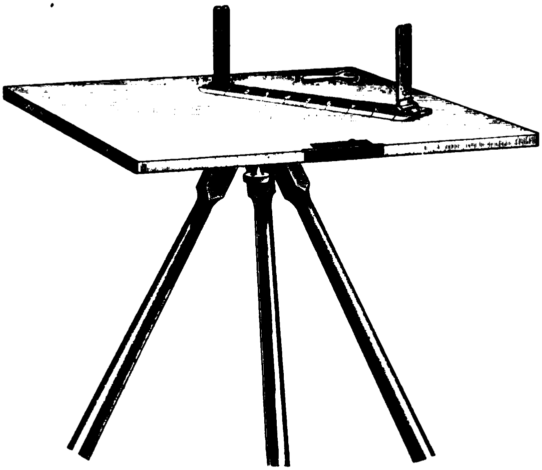


Fig. 10.—The plane-table and alidade.

42. The Plane Table Method.—The method just described is a clumsy one at best, and we have a much easier one that involves the use of the *plane-table*. This is nothing more than a drawing board mounted on a tripod in a way that allows it to revolve. The direction of all desired points is taken by sighting with the *alidade,* after the board is properly set up, but it is essential first to have a *base-line* from which to work. This line is taken is a measured length usually about one-third of the length of the field, and is drawn to a chosen scale upon the map. When a plane-table is set up over a known point, approximately level and with its base-line extending in the same direction as the base-line in the field, either coincident with or parallel to it, it is said to be properly *oriented.*

43. The Principle of the Plane-Table.—Fig. 11 illustrates the principle of the plane-table in diagram. Let C D E F G be the irregular field and A B the chosen base-line. It is usually easy to see at a glance what the general position of the map on the paper should be in order to present the neatest appearance. One side of the table should be approximately parallel to the longest side of the field, in this case to F G. Select the point *a* to represent A, where judgment or rough measurements seem to dictate. With *a* over A, and the board in the desired position, put one end of the alidade on *a,* move the other end until B is sighted, and draw a line along the straight-edge of the alidade. Locate a point *b* on this line at such a distance from *a* that it will represent the point B at the proper scale, in this case 1:4. The line *ab* represents A B, and the board is oriented and ready for use.

With the straight-edge of the alidade again on *a,* revolve it upon that point as an axis until F is sighted. Indicate its direction by a *direction-line.* Similarly obtain and indicate the direction of each corner of the field, and that of any interior point as M.

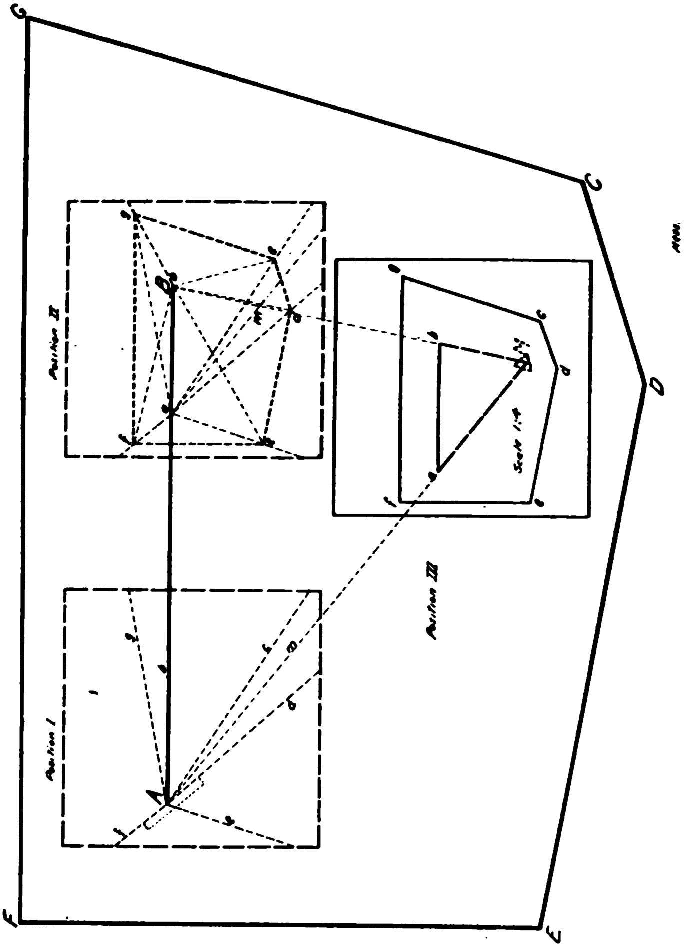


Fig. 11.—The principle of the plane-table in diagram.

Then set the table with *b* approximately over B and with *a* extending in the direction of A. Perfect the orientation with the alidade. Then using *b* as an axis obtain and indicate the direction of F. It is evident that this point as well as all other points will not lie in the same direction from the table in Position II as in Position I, and upon this fact the principle of the plane-table method of location depends. The direction of F being different now, the line drawn from *b* in this new direction will intersect the line drawn toward F in Position I. This intersection marks the location of *b* on the map, and similar intersections of corresponding lines will mark the location of the other corners of the field. Finally, the beauty of it all is that the distance between these intersections on the map will be proportional to the distance between the corresponding points in the field, and the former will bear the same ratio to the latter as the base-line on the map does to the base-line in the field. In other words, *cdefg* is a true reproduction of C D E F G at a reduced scale.

44. Details of Manipulation.—The care taken in making the plane-table horizontal should depend upon the accuracy required in the work. It is evident that the line of sight should lie in a vertical plane parallel to the one in which the straight edge of the alidade lies, and the table must be horizontal before this will be the case for all positions of the alidade.

A plumb-bob facilitates the matter of getting the point *a* over A in the field, but a pebble dropped from a point on the under side of the table approximately under *a* will answer the same purpose, because if the error is not greater than an inch, for large areas it is practically correct. Where the point sighted is 1,000 feet distant, two lines starting an inch apart at the table and converging at the point, may be assumed to be parallel. The percentage of error will be only 1 inch in 1,000 feet or 1:12,000, which is inconsiderate indeed, especially when mapping areas for drainage purposes. At any rate if the lines were an inch apart at both ends, they would be parallel, and an error of that much is apt to occur with the best of care in either holding the flag to be sighted at, or in sighting unless an alidade with telescopic sights is used.

On the other hand, great care must be taken in orientation. It is wise to check the orientation by sighting occasionally at the other end of the base line, or at any other known point. An error in *orientation* means an error in the relative direction of the line of sight. Such an error is magnified in direct proportion to the length of the line of sight, while an error in *position* is minimized in direct proportion to the length of that line.

45. Orientation on a Known Point.—In case there is a corner of the field that is not visible from either A' or B, it is convenient to have a third point as M from which it is visible. In any case, it is well to know that locations may be made from this point as well as from either A or B. Set up the table over M and place the alidade on the line *ma*. Revolve the table until the flag on the point A is sighted. Then since the line *ab* and A B from equal angles with the line A' M, they are parallel to each other, and hence in one of the two conditions either of which satisfy the definition of orientation (**42**). As a check, after orientation is made on A, put the alidade on *mb* and see if B is sighted. Similarly sight at G or any other point already located. Finally locate the points, if there are any, invisible from either A or B, or both. In the latter case, a fourth position will have to be taken and oriented from.

It sometimes happens that the direction-lines drawn for a point are very nearly parallel. Where this is the case it is best to take one observation from the third point because the more nearly a right angle the direction-lines are at their intersection, the more accurate the locaton will be.

46. Resection From Three Known Points.—Suppose that X is a desirable point over which to set up the plane-table, yet its location, *x* on the map, is not known. The points G, C and D have been located, and there is a method by which X may be located from them. Level up the table over X, without any thought of orientation, and tack some tracing paper upon it. Select any point *x′* and draw lines from it in the direction of each of the three known points. These lines should be at least long enough to represent, according to scale, the lines for which they stand. They show the angular relation existing between X and the three known points. Here it must be remembered that unless X lies in the circumference of a circle passing also through G, C and D, this angular relation is peculiar to the one point X. Knowing this, it is evident that if a point is found on the map which bears the same relation to g, c and d as X does to G, C and D, it will mark the location of *x*. To find this point, make the tracing cloth free from the board and slide it over the map until a position is finally found in which each line is over its corresponding point. A pin pricked through thetracing paper at x' shows where x should be on the map. Then, and not before, is orientation from X possible.

47. Practical Application.—The principle and simpler manipulations of the plane-table have been dwelt upon in detail because this method of mapping lends itself so well to the mapping of areas for drainage purposes. Even though but a crude plane-table map is ito be made, it is essential to understand thoroughly the why and wherefore of principles involved.

A plane-table does not need to be a fancy instrument. A heavy stake driven at the end of the base line upon which a board may be temporarily nailed will answer the purpose in many cases. Where this device is used the base-line should perhaps be drawn in the right direction after the table has been nailed or tacked in place. After all sightings have been made, the board may be similarly mounted at the other end of the base-line. In the absence of a better one, two pins, one stuck at the axis and the other moved by the hand until it is in line with the point sighted, will serve the purposes of an alidade.

The plane-tables used by the students at this college were designed for that purpose by Mr. Walter Pratt of Beloit. A farmer could have one made for a dollar. They consist essentially of a drawing-board of inch material to which a casting is fastened at the center by screws. A bolt-like projection with threads for a thumb-nut extends down through another casting to which the three legs are attached. Where the upper casting has a convex surface to fit into a concave surface on the lower one, it acts like a ball-and-socket joint. The opening in the latter, however, must be enough larger than the bolt to allow it to slide. Later the table is clamped by means of the thumb-nut and a washer.

CHAPTER VI.

THE USE OF THE LEVEL.

A *level line* is one perpendicular to the direction of gravity. The *elevation* of a point is its vertical distance from a *datum plane,* usually the sea-level. This plane is said to have a zero elevation.

48. Absolute and Relative Elevations.—The waterway in the head of a valley has an *absolute* elevation frequently greater than that of the sides of the same valley near the outlet. Nevertheless the sides are said to have a greater *relative* elevation because they are compared with a point in the waterway between them. It is the relative elevation of land that determines the quality of its natural drainage. This is well illustrated in Fig. 16.

49. Devices for Leveling.—A *level* is an instrument used to determine the elevation of a point. The surface of water in a pond is nature's most unerring level, but just a little liquid enclosed in a tube, is easier to handle and will answer the same purpose. The simplest form is that of the carpenter's level, consisting of a simple bubble tube parallel to one side of its mounting. Points on the earth's surface, the difference of whose elevation is sought, are usually so far apart that neither the level nor the straight-edge on which it may be placed can be conveniently made long enough to reach between them. For this reason a line of sight parallel to the bubble-tube is used. Differences may be roughly determined by centering the bubble of a carpenter's level over the higher of two points and sighting in the direction of the lower. The distance between the horizontal line of sight and the bottom of a rod held vertically on the lower point, is the difference in elevation.

The *rod,* preferably graduated to tenths and hundredths of a foot, is thus the necessary companion of the level. More accurate readings can be taken when the level is provided with sights. Another scheme is to have a curved glass tube about an inch in diameter and containing a colored liquid which rises in both arms of the curve. A line of sight over the top of the two columns is horizontal and may be used for determining comparative elevations.

50. The Telescopic Level.—Readings by any of these crude methods will be inexact, and for this reason a telescopic line of sight is used. The cross-wire in the field of vision should mark the projection of the horizontal line of sight on the rod, when the bubble is centered. Ordinary magnification makes it possible to read the rod to thousandths of a foot when held 300 feet away.

A direct reading may be taken upon the rod, or the target may be made to slide up or down by the rodman until the cross wire coincides with the line between the red and the white on its face. In the former case the rod is called a *speaking* rod. In the latter, the reading may be taken to thousandths by means of the vernier shown in Fig. 12. Read the feet first, then the tenths, and then the last hundredth mark below the line between the red and the white. Ten marks on the vernier are equal to nine on the rod, and hence the difference between the width of a space on the rod and that

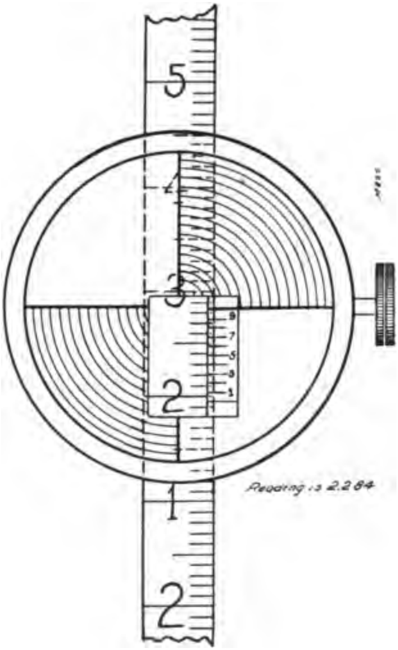


Fig. 12.—The vernier target. Always read the last hundreth mark on the rod below the dividing line on the target.

of one on the vernier is a thousandth of a foot. The marks on the vernier are so numbered that the one which coincides with a mark on the rod indicates the number of thousandths. The reading is thus 2.284.

There are three general types of telescopic levels that will be considered here:

(1) The *Wye* level; (2) the *Dumpy* level, and (3) the *Drainage* level. The essential difference between them lies in the manner in which their parts are fastened together. The Wye level (Fig. 13), takes its name from the Y shaped posts that support the telescope tube. By unclamping the Y's the tube may be removed and rotated. This cannot be done with a Dumpy level. The Drainage level (Fig. 14) is a cheaper grade of instrument. This level does very well for the short lines of levels that usually need to be run for drainage purposes, but it is the height of folly to assume that the levels run for a line of tile may be any less accurate than those run for a railroad. A gradient of a tenth of a foot in 100, one way or the other, makes practically no difference to the locomotive propelled by

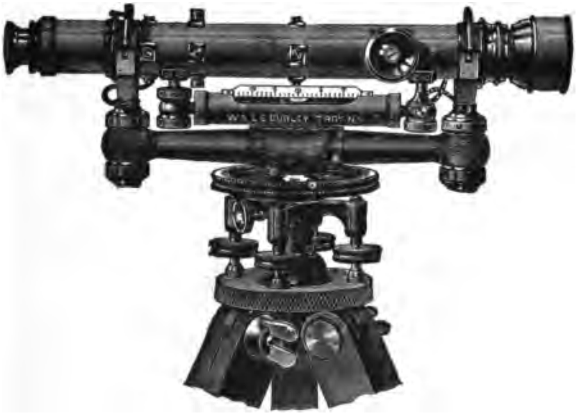


Fig. 13.—The Wye level.

steam, but with gravity for the motor power, the presence or absence of that amount of fall in 100 feet of a line of tile is a factor well worth considering. Be that as it may, one should learn to run accurate levels irrespective of the occasion.

51. The Line of Levels.—The simplest operation with the level is to find the difference in elevaation between two points as A and B, not more than 600 feet apart. The level mounted on a tripod is set up and leveled midway between the two points. Suppose a reading of 2.0 is taken on A. This means that A is two feet lower than the height of instrument which is abbreviated to H. I. If, when the level is revolved on its axis to the direction of B, without moving the tripod or changing the H. I., and a rod held at B is read at 3.0, it indicates that B is three feet lower than the

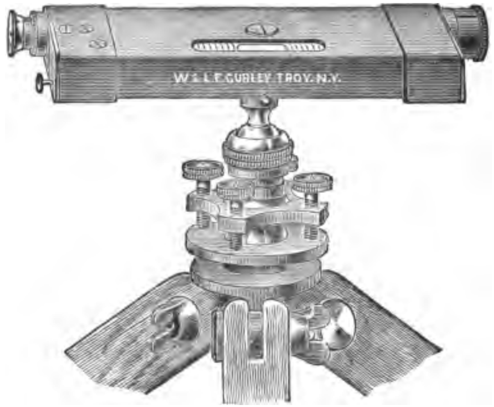

W. & L. E. GURLEY TROY. N.Y.

Fig. 14.—The "Drainage" level. When properly adjusted, instruments of this general type suffice for the short lines of levels that are usually necessary for small drainage systems. They must be accurate, however, for no work requires such careful levelling as does drainage by gravity.

H. I. But A was two feet lower than the H. I. Therefore B must be one foot lower than A. *The difference between the rod readings on any two points from the same H. I. is the difference between their elevations, and the larger rod reading is always on the lower point.*

When the two points are more than 600 feet apart a *line of levels* must be run between them. *A bench mark* is a fixed point at the beginning of a line of levels, whose elevation is assumed to be a convenient distance above the datum plane. It should be a point that will remain undisturbed for years.

A diagramatic representation of the elevations of a succession of points is known as a *profile.* Some points in the profile may be found to be lower than the bench-mark, but the elevation of the latter should have been so chosen in the first place, that the profile will never come below the datum plane. This eliminates the necessity of using minus quantities.

To run a line of levels from A to B, let A be the bench-mark with an elevation of 50.00. Set up the instrument in the direction of B and 300 feet distant from A (100 feet if a Drainage level is used). Take a *back-sight* (B. S.) reading on A and *add* it to 50.00 to find the H. I. Revolve the level in the direction of B and put in a pin or stake approximately equidistant with A. Such a stake is called a *turning-point* and its elevation is found by *subtracting* the *fore-sight* (F. S.) taken upon it from the H. I. The level is then taken 300 feet ahead of the turning-point where it is set up and again leveled. The B. S. taken on the turning-point added to the elevation *of the turning-point* gives the new H. I. A new turning-point is then put in ahead and thus step by step progress is made toward B. The distance will be shorter if the line is run straight for B, but aside from that, no harm is done in taking a curved or irregular course. In fact it is often best to run around a hill that may happen to intervene. This eliminates the necessity of carrying the elevations over the hill where short sights would be necessary. However, the same elevation should be obtained for B, regardless of the direction in which the line was run.

The columns in the level-book should be arranged as follows:

TABLE IV.

A method of recording level-notes.

Sta.	B. S.	H. I.	F. S.	Elev.	PACES.		Remarks.
					B. S.	F. S	
A.	3.124	....	....	50.000	100	......	Davis, levelman.
T. P.	3.288	53.124	4.122	49.002	100	100	Roberts, rodman.
T. P.	5.895	52.290	4 671	47.619	80	100	Jan. 8, 1908.
B.	3.284	53.514	3.284	50.230	100	80	Waterway.
T. P.	3.627	53.514	4.100	49.414	100	100	
T. P.	4.824	53.041	3 821	49.220	90	100	
A.	....	54.044	4.036	50.008	......	90	Error of closure: .008.
					570	570	

It will be noticed in the above notes that the elevation of a point, the H. I. from which that elevation was determined, and the F. S. and the B. S. taken upon that point, appear with it on the same line.

52. The Error of Closure.—The notes also show that it is customary to end every circuit of levels at the point where it began. After B has been reached, levels should be run back either over the same path or over another one, to A. If A has been undisturbed in the meantime, it should still have an elevation of 50.000. The error which is almost unavoidable, is the *error of closure.* This should never be more than .05 feet times the square root of the distance in miles.

At any time after the elevation of a point has been found, the difference between the sum of all the B. S. readings and that of all the F. S. readings, should equal the difference between the elevation of that point and that of the bench-mark. This is a quick method of checking when a search is being made for an error in addition or subtraction.

53. Let One Man Check the Accuracy of the Other—Specific Directions.—An error in a single reading will throw the whole line of levels off. An error in addition or subtraction can be discovered and corrected, but one in the reading, once made, can never be located, much less corrected. Hence, great care must be taken in reading the rod. The rodman should read the rod and enter the reading in his book, before he lets the levelman see it at all. Then he shows the rod to the levelman who reads it out loud, and the rodman listens to hear whether this reading is the same as the one he has recorded in his book. If not, right there and then, each reads the rod again, to see which, if either, was right. If this method is followed, one man checks the accuracy of the other, and each reading the rod independently of the other, the same mistake is not apt to be made by both.

The following directions for setting up the level and taking the reading appearing also in Bulletin 138 (Wis.), should be kept in mind by every levelman.

Plant the legs of the tripod firmly in the ground, with *one pair of levelling screws in line with the two points. Keep the horizontal plate upon which the levelling screws rest as nearly horizontal as possible, so that the work of centering the bubble with the levelling screws will be small. This done, center the bubble approximately first over one pair of screws and then over the other; then accurately over the first pair and likewise over the second, until the bubble remains centered for both positions.*

Then "find" the rod through the telescope and have the rodman slide the target up or down until the cross hair hits approximately the dividing line between the red and the white. Without changing the direction of the telescope, see that the bubble is centered. Have the rodman slide the target to exactly the right place, and look at the bubble again. If still centered, signal to the rodman to clamp the target; if not, look at the bubble and through the telescope tube alternately until you are sure that the cross hair hits the center of the target at a time when the bubble was centered. This being important, a level must be so made that the bubble can be thus centered without changing the height of instrument. When the level is turned half way around after taking a back sight, always see that the bubble is centered before a 'fore sight is taken.

CHAPTER VII.

THE ADJUSTMENTS OF THE LEVEL.

The accuracy of the methods outlined in the last chapter will depend largely upon whether or not the instrument is in proper *adjustment*. That is, the line of sight must be parallel to the bubble-tube. If it tends to diverge upward from the bubble-tube the rod reading taken at 300 feet will be larger than it ought to be. If the level is revolved and a F. S. is taken also at 300 feet, in the other direction, this reading will likewise be too great, and by the same amount because the two stations were equidistant. The error will thus disappear by subtraction. It is for this reason that the level should always be set up as nearly as possible *midway between* the two points in question. There are occasions, however (**59**), when it is inexpedient to have the F. S. and the B. S. of equal length. At any rate it is well to know how to test the adjustment of an instrument and how to correct the adjustment if it is found to be faulty. The level should be tested before each day's work.

54. Adjustments of the Wye Level.

Adjustment I.

To Make the Line of Sight Coincide with the Geometric Axis of the Telescope Tube.

Set the level up firmly with one pair of diagonally opposite levelling screws in line with a distant object to be sighted at. Focus the telescope upon the object, clamp the horizontal motion, and by means of the leveling screws make the horizontal cross hair hit a particular point. Rotate the telescope tube through 180 degrees upon its axis in the Y's, and see if the cross hair still falls upon the distant point. If so, the adjustment is already correct; if not, bring the cross hair half-way back to that point by means of the capstan headed screws, and bring it the rest of the way back by means of the levelling screws.

Check: Rotate the telescope through 180 degrees again, and see if the cross hair still falls upon the distant point. If not, repeat the process until it does.

The line of sight is then coincident with the axis of the telescope tube, and assuming that the rings are the same size, it is parallel to axis of the Y's.

Adjustment II.

To Make the Bubble Tube Parallel to the Axis of the Y's and hence to the Line of Sight.

With the level firmly set up center the bubble first over one pair of levelling screws and then over the other.

Center it more carefully over the first pair, and clamp the horizontal motion. Remove the telescope from the Y's, change it end for end, and set it back. If the bubble is still centered the adjustment is correct; if not, bring the bubble half-way back to the center by means of the adjusting screws at the ends of the bubble tube. Then center the bubble by means of the levelling screws.

Check: Change the telescope tube end for end in the Y's again and see if the bubble remains centered.

Adjustment III.

To Make the Bubble Tube Perpendicular to the Axis of Revolution.

After Adjustment II has been completed, the telescope tube is clamped in the Y's, and the bubble is carefully centered. The horizontal clamp is loosened, and the level is revolved through 180 degrees upon the axis of revolution. The bubble should still be centered; if not, bring it half-way to the center by means of the big screw at the bottom of one of the Y posts. Bring the bubble the rest of the way back by means of the levelling screws.

Check: Revolve through 180 degrees.

55. Adjustments of the Dumpy Level.

Adjustment I.

To Make the Bubble Tube Perpendicular to the Axis of Revolution.

Center the bubble over both pairs of levelling screws, and then more carefully over one particular pair. Re-

volve through 180 degrees. The bubble should still be centered; if not, bring it half-way back to the center by means of the adjusting screws at the end of the bubble tube. Bring it the rest of the way back by means of the levelling screws.

Check: Revolve through 180 degrees.

Adjustment II.

To Make the Line of Sight Parallel to the Bubble Tube.

(Peg Method).

Select two firm points A and B about 300 feet apart, on reasonably level ground, and set up the level mid-way between them, with one pair of diagonally opposite levelling screws in line with them. Take a rod-reading on each point. If the points are exactly equidistant the error, if any, due to the instrument being out of adjustment, will disappear with the subtraction, and the true difference of elevation between the two points may be determined.

Now set up the level immediately in front of A. Take a rod-reading upon A by looking through the telescope from the objective end. From the known difference of elevation compute the proper rod-reading for B, and set the target accordingly. Hold the rod upon B and see if, with the bubble centered, the cross-hair hits the center of the target; if not, by means of the capstan headed screws, move the cross hair up or down until it does. The line of sight is now horizontal, and hence if the bubble is centered, it is parallel to the bubble tube.

Check: No check is necessary if the readings have been carefully taken.

56. The Adjustment of the Drainage Level.

Adjustment I.

To Make the Bubble Tube Parallel to One, and hence to Both of the Faces of the Mounting.

Remove the level from the tripod and place one of its parallel faces upon a smooth surface approximately level. Note the position of the bubble. Change the level end for end, but upon the same spot. If the bubble is in the same position as formerly with reference to the surface, the adjustment is perfect. If not, bring the bubble halfway back to that position by means of the adjusting screws at the end of the bubble tube.

Check: Change end for end once more.

Adjustment II.

To Make the Line of Sight Parallel to the Faces of the Mounting and hence to the Bubble Tube.

Place one of the parallel faces of the level on a smooth surface and focus the telescope on a point at least 200 feet distant. Turn it on its opposite face and see if the line of sight hits the same point as formerly. If not raise or lower one end of the telescope-tube in the mounting by means of the screw at its end until the line of sight is brought to a new point half way back to the point originally sighted. The line of sight and the bubble-tube, each being parallel to the faces of the mounting (they were made so by the manufacturer) are hence parallel to each other.

Check: Invert the level once more and see if it still hits the new point.

Adjustment III.

To Make the Bubble Tube and hence the Line of Sight Perpendicular to the Axis of Revolution.

Put the level back upon the tripod and center the bubble without disturbing the ball-and-socket joint. Revolve through 180 degrees and see if the bubble is still centered. If not, bring it half way back to the center by means of the screw that fastens the mounting to the shaft.

Check: Center the bubble once more by means of the levelling screws and revolve through 180 degrees.

CHAPTER VIII.

THE TOPOGRAPHIC MAP.

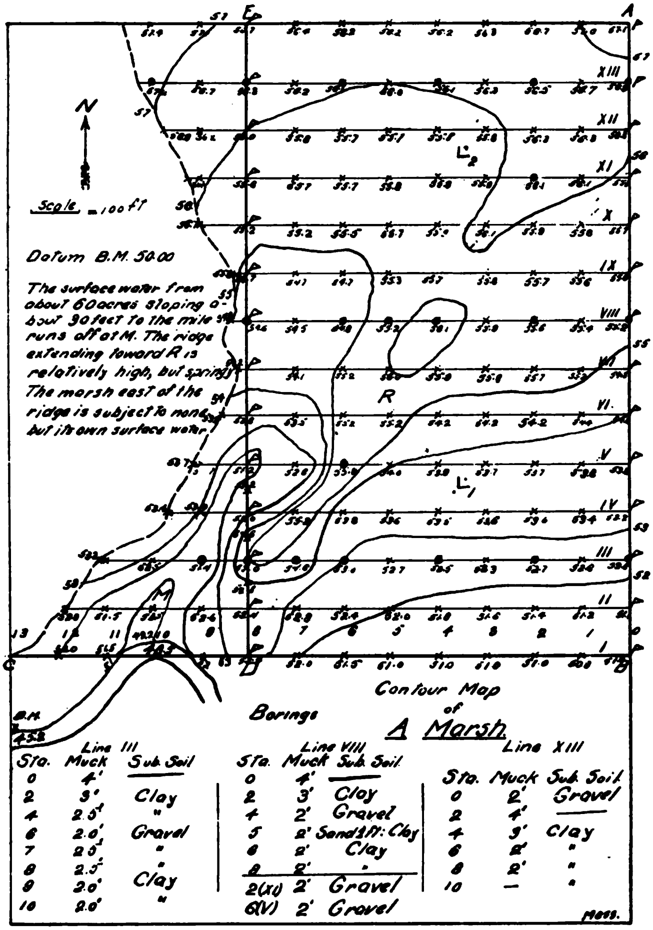
A *topographic map* is one upon which locations are made in both the horizontal and the vertical plane. In other words, it is a map which shows not only horizontal distances, but also elevations. The elevations are indicated by means of *contour lines,* which pass through points having the same elevation. The datum elevation should be included in the legend of such a map.

56. Upland Versus Lowland.—The U. S. Geological Survey has made topographic maps of a large portion of the country, mapping the high land as well as the lowland. The slope of the surrounding upland is a factor in the drainage of the lowland (**73, 107, 141**), but where this slope is enough to affect the problem seriously it is usually evident to the eye. For this reason when mapping topography for drainage purposes, it is that of the lowland that is primarily sought.

57. The Points That Need to be Located.—In the topography of a marsh there are three distinct kinds of points that should be located and whose elevations should be found out. They are where there is a decided change (1) in the direction of the main waterway, (2) in the outline of the marsh, or (3) in the profile of the traverse described by either one, chiefly the former, of these two successions of points. These points should be taken with such frequency that either the direction or the slope between them may for all practical purposes be assumed to be uniform, that is, in a straight line. These points may be located by any one of the methods described in **40, 41** or **42.** The lines they limit may be called *skeleton-lines.* The cross-section method and the plane-table method are most frequently used.

58. The Cross Section Method.—This method lends itself well to an area comparatively uniform in outline as the one shown in Fig. 15. Flags are set at intervals of 100 feet along two parallel lines in the field, each flag on the one line being visible from its corresponding point on the other. Side AB is taken as one line because it is straight and at right angles to the side BC. At D, 800 feet from B, a perpendicular DE is staked out, which is hence parallel to AB, and will suffice for the other line. With the flags put in, all is in readiness to commence taking the elevations.

59. Running the Levels.—Levels are run from the B. M. to a convenient point L, where the level is set up and the H. I. is ascertained by taking a B. S. on the last known T. P. The rodman holds the rod at B and the reading is taken. To be accurate, the line BD should be divided into 100-foot spaces with a chain, but with experience the rodman should be able to pace off this distance sufficiently accurate for all practical purposes. He paces straight for the flag on DE, stopping for readings every 33 or 35 paces, according to the length of the pace. Station 7 is perhaps the last one on Line I upon which readings had better be taken from the set-



The surface water from about 60 acres sloping about 90 feet to the mile runs off at M. The ridge extending toward R is relatively high, but springy. The marsh east of the ridge is subject to none but its own surface water.

Borings

Line III

Sta.	Muck	Sub Soil
0	4'	—
2	3'	Clay
4	2.5'	"
6	2.0'	Gravel
7	2.5'	"
8	2.5'	"
9	2.0'	Clay
10	2.0'	"

Line VIII

Sta.	Muck	Sub Soil
0	4'	—
2	3'	Clay
4	2'	Gravel
5	2'	Sand 1 ft: Clay
6	2'	Clay
8	2'	"
2(XI)	2'	Gravel
6(V)	2'	Gravel

Line XIII

Sta.	Muck	Sub Soil
0	2'	Gravel
2	4'	—
4	3'	Clay
6	2'	"
8	2'	"
10	—	"

Fig. 15.—A topographic map made by the use of 100-foot squares.

up at L, so the rodman, after marking this point, goes back to Station 0 on Line II, from which point he advances by stations toward the corresponding flag on DE. This can be done from this same set-up, on all lines up to and including Line VIII, when the level is taken to some other convenient point as L_2 from which some more readings may be taken. The new H. I. must be determined by a reading on the T. P., which should have been previously put in for this purpose. These long sights are warranted only on the assumption that the instrument is a good one and in adjustment, that it is firmly set up, and that care is taken to center the bubble for each reading. The latter requires particular attention because the marshy ground on which the levelman is sometimes compelled to set his level is frequently so soft that he cannot shift the weight of his body from one foot to the other when standing near the instrument, without throwing the bubble out of center. Some levels are provided with mirrors which reflect the bubble to one eye of the levelman while with the other eye he is taking the rod readings. The readings on the T. P.'s in this work are taken to hundredths, and as such, are used in computing for the H. I. or for the elevation of a new T. P. The readings on the ground are taken only to tenths, and to be consistent, the H. I., when used to find the elevataion of the ground from these readings, is also given a value which is the nearest tenth to the more exact value. If it is midway between as 56.75 for the rough readings it would be called 56.8.

60. Checking the Elevations.—When a new set-up is made and the H. I. determined, readings should be taken on one or two points whose elevations have already been found, to see if the same elevations are found from the new position. If the respective elevations of any two points is found to be different from their former rescpective elevations and by the same amount in each case, it is good evidence that a mistake of that amount has been made in computing the new H. I.

61. Keeping the Notes.—Level notes for taking topography in this manner should appear as follows:

TABLE V.

A method of keeping level-notes when taking topography.

Line.	Station.	B. S.	H. I.	F. S.	Elevation.	Remarks.
....	....	3.14	58.90	....	55.76	T. P. on the ridge.
....	....	....	"	2.87	56.03	T. P. 300 ft. N. of L.
I	0	....	"	7.9	51.0	
"	1	....	"	8.1	50.8	
"	2	....	"	7.9	51.0	
"	3	....	"	7.9	51.0	Jan. 7, 1908.
"	4 etc.	....	"	7.9	51.0	Morris, levelman.
VIII	0	....	"	3.7	55.2	Richards, rodman.
"	1	....	"	3.5	55.4	
"	2 etc.	....	"	3.3	55.6	
....	....	3.66	59.69	....	(56.03)	The above T. P.
....	....	....	(59.7)	14.13	55.56	T. P. 300 ft. W. of L_2.
VIII	1	....	"	4.3	55.4	Check.
"	2	....	"	4.1	55.6	Check.
IX	0	....	"	4.1	55.6	
"	1 etc.	.... .	"	4.1	55.6	

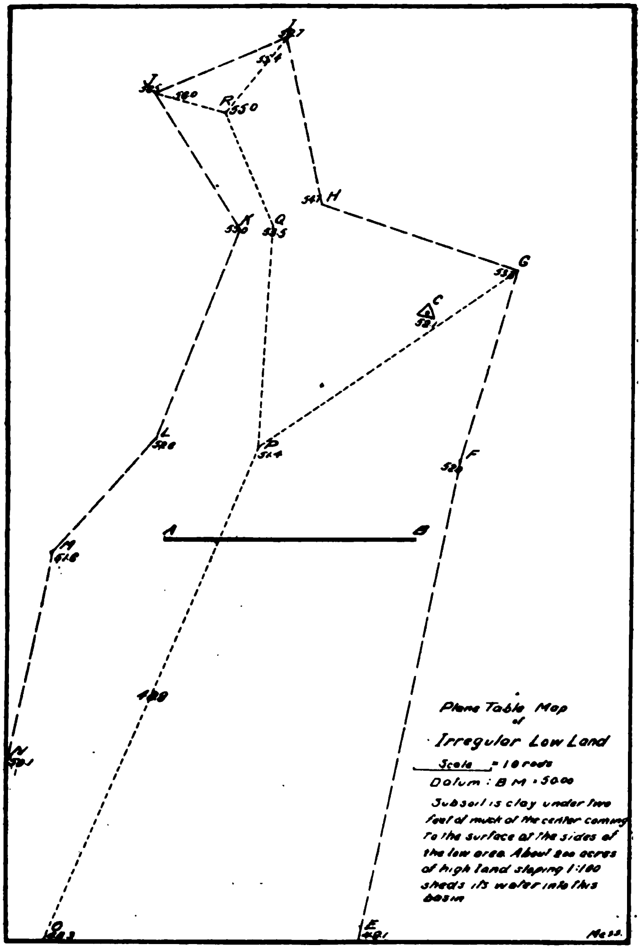
62. The Rectangular Sub-division.—A glance at the map shows that the marsh has been divided into 100-foot squares the elevation of every corner of which is known. Corresponding stations should be in line. It will be remembered that the line DE was put in at an even station on Line I. Hence the rodman will have an opportunity to check the accuracy of his pacing by his proximity to the flag upon reaching Sta. 8 on any of the interior lines. If he should fall a little short, or over-lap a trifle it is probable that the same has been the case on all of the lines and the "squares" are at least rectangular, and of known dimensions.

The rodman should keep his eye on the flag ahead continually while pacing distances toward Sta. 8 on any line. After he has passed that station he obtains his line by sighting back at the two flags after he has stepped off the required distance. Where it seems desirable (**57**) to take intermediate readings, this should be done.

63. Putting in the Contour Lines.—With the elevations taken, the next step is to put in the contour lines. Begin with the lowest and then put in the next one above it, etc. On this particular map the *contour interval* in one foot. Facts well worth remembering are (1) that contour lines, beginning with the lowest, should be made to extend *around* all points of that elevation or lower; (2) they are either circular or else end at the border of the area mapped; (3) they never cross each other; (4) they seldom make sharp turns, and (5) they always run between two cross-section corners, one of which is higher, and the other of which is equal to or lower than their own elevation, and the distance from each should be governed by those differences.

The squares may be made larger than 100 feet in size, but, of course, the map is not so accurate unless there is a marked uniformity in topography.

63. Irregular Areas.—A method which will yield the same results but with less work, on irregular areas, like that shown in Fig. 16, involves the use of the


I
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E
Plane Table Map
of
Irregular Low Land
Scale = 10 rods
Datum : B M = 50.00
Subsoil is clay under two feet at much of the center coming to the surface at the sides of the low area. About 200 acres of high land sloping 1:100 sheds its water into this basin
Ness.

Fig. 16.—A map made by the plane-table method.

plane-table. The points mentioned in (57) are located by this method, after a flag has been put up at each, except those at which the profile changes. There they are unnecessary because they can be located by the rodman when pacing along any of the *skeleton-lines* with flags at their respective ends. He enters a note of the distance from the beginning of the line as well as the rod-reading every time he holds the rod. For example, the point observed near C would be described as P+450 feet on skeleton-line PC. The same percautions in the use of the level hold here as were given for the cross-section method. Contour lines may be similarly put in from the elevations obtained.

64. Tracing the Contour Line in the Field.—Another method of locating the contour lines by means of a level is to set the target at a rod-reading equal to the difference between the H. I. and contour sought. If, for example, the H. I. is 56.0, any point at which the target set at 2.0 and held is hit by the line of sight, but from which the elevation increases in any direction, marks the location of the 54th contour line. By finding the succession of points that fulfill this requirement, the contour line may be traced in the field, and located on the map by reference to known points.

The telescopic hand level is convenient for doing rough contour work. It contains the image of a bubble in the field of vision and the observer can see that the bubble is centered, and at the same time note the point on the ground cut by the line of sight. As the field of vision is swept across the area to be mapped, the succession of points observed marks the path of the contour line. The observer then takes a position in the contour line just located and repeats the operation for the next one. In this case the contour interval is the vertical distance between the eye of the observer and the earth.

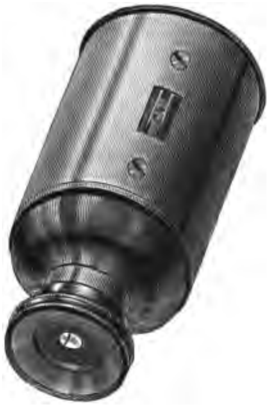

Fig. 17.—A monocular hand-level.

These and other methods are used in making the topographic map, but the ultimate object of them all is to find and represent graphically the relation between the fall of the earth's surface and the horizontal distance over which it is distributed—a relation which is paramount in the considerations on land drainage which are to follow.

QUESTIONS ON PART I.

CHAPTER I.

1. **Define surveying.**
2. **Discuss its relation to land-drainage.**
3. **Define (1) compensating error; (2) cumulative error. Give an example of each.**

CHAPTER II.

4. **Describe (1) the engineer's chain; (2) Gunter's chain; (3) the steel ribbon; (4) the metallic tape.**
5. **Describe the method of standardizing a chain.**
6. **State the advantages and disadvantages of (1) chains; (2) metallic tapes; (3) steel ribbons.**
7. **What is meant by chaining?**
8. **Define and discuss the importance of alignment.**
9. **Describe the see-saw method of alignment.**
10. **What is meant by "breaking chain"? When is it necessary?**
11. **Classify the errors common in chaining, according to their character.**
12. **Describe, in detail, the method of chaining.**
13. **What is meant by "tallying"? Describe one method of tallying.**
14. **Give examples of distances that may be measured with sufficient accuracy by pacing.**
15. **Describe the stadia method of measuring distances.**
16. **What is a random line? When is it used?**

CHAPTER III.

17. **Describe two methods of measuring an angle with a tape.**
18. **Describe the instruments of accuracy, used to measure angles.**
19. **Explain the principle of the vernier scale.**
20. **What two readings are necessary in all angular measurements?**

21. Define (1) forward azimuth; (2) rear azimuth; (3) traverse.
22. What is a compass? Define (1) declination; (2) agonic line; (3) magnetic bearing; (4) true bearing.
23. Discuss the practical application of angular measurement to land drainage.

CHAPTER IV.

24. State the history of (1) the acre; (2) early methods of land sub-division; (3) the present method.
25. Define (1) congressional township; (2) base-line; (3) principal meridian; (4) standard parallel; (5) guide meridian; (6) range-line; (7) township-line.
26. Describe in detail the method of procedure in subdividing a "block" of land.
27. Describe the monuments used.
28. Discuss the causes of the irregularity in the size of the west row of forties in a township.
29. Discuss the relation between the base line and the standard parallels.

CHAPTER V.

30. Define (1) map; (2) scale; (3) legend.
31. Define (1) plane-table; (2) alidade; (3) base-line; (4) orientation; (5) direction-line.
32. Why should the plane-table be horizontal?
33. Compare an error of position with an error of orientation.
34. In what cases is it convenient to set up over a third point?
35. Describe the process of resection from three known points.

CHAPTER VI.

36. Define (1) level line; (2) absolute elevation; (3) relative elevation; (4) datum plane; (5) a level; (6) profile.
37. Name two simple devices for levelling and the disadvantages of each.
38. What is a speaking rod? When can they be used?
39. Describe briefly three kinds of telescopic levels. When is a "line of levels" necessary?

    Define (1) height of instrument; (2) back-sight; (3) fore-sight; (4) bench mark; (5) turning-point.
40. Describe the method of changing from one datum to another.

41. Why is it hard to carry a line of levels over a hill?
42. Define "error of closure." Explain.
43. State a quick method of checking the notes for correctness of addition and subtraction.
44. Outline a method by which the rodman and level man will check each other's mistakes.
45. Name the two most important factors of accurate levelling.
46. Classify the errors peculiar to levelling.

CHAPTER VII.

47. Name the ultimate object sought in adjusting a level.
48. Why is it best to set up the level mid-way between the two points upon which readings are to be taken?
49. Is there any other reason why the F. S. and the B. S. should be equal?
50. When is it convenient to be able to take sights of unequal length?
51. Describe the adjustments and the check for each of the adjustments of the Wye Level.
52. Describe those of the Dumpy Level.
53. Those of the Drainage Level.
54. Which of the adjustments of the Wye level is of least importance? Which of those of the Drainage Level? Why?
55. In what respect does Adjustment II of the Dumpy level differ from any and all of the other adjustments?

CHAPTER VIII.

56. Define (1) topographic map; (2) contour line; (3) contour interval.
57. What is a "skeleton-line"?
58. Name the three classes of points that must be located.
59. Describe the method of laying out cross-sections squares.
60. On what conditions may long sights be taken with a level?
60. Describe a method of checking the accuracy of a new H. I.
62. Name five properties of contour lines.
63. Describe two methods of tracing a contour line in the field.

PROBLEMS IN PART I.

1. A line was measured with an unstandardized 50-foot metallic tape, and found to be 822.4 feet long. Later, the tape was standardized and found to be 0.07 feet too long. Assuming the stretch to be evenly distributed, what was the true length of the line?

2. A line measured by a steel ribbon was found to have a length of 1920.7 feet. After the last reading had been taken, it was noticed that the head chainman had been setting the pins at a point 0.11 feet past the 100-foot mark on the tape. What was the true length of the line?

3. A 100-foot engineers' chain was standardized and a mark was made upon it with a file, 0.22 feet back of the original 100-foot mark. Using this new mark, a line 1000 feet long was laid out. Later, upon re-standardization, it was found that the corrected mark should have been 0.12 feet, instead of 0.22 feet, from the original mark. What was the true length of the line?

4. The true length of a line is known to be 1000 feet. How long would this line be found to be, if it were to be remeasured with the unstandardized chain used in Problem 3? If measured by that chain, when the incorrect mark was used?

5. Two sides of a field are 75 rods and 60 rods long, respectively. They are parallel to each other, and are perpendicular to one end, which is 40 rods long. What is the area of the field in acres? In square chains?

6. What is the value of angle x if b is taken as 30 feet and a is found to be 14.7 feet?

7. Give the proof and the check for a method of

(1) Erecting a perpendicular to a given line at a given point.

(2) Laying out a rectangle.

(3) Dropping a perpendicular from a given point to a given line.

8. Devise a method of measuring the distance to a visible but inaccessible object. Give proof.

9. Devise a method of chaining around an obstacle. Give proof and check.
10. Find the area of a triangle whose sides are 24, 28, and 42 rods respectively.
11. A random line at the end of six miles is found to be 9 chains and 36 links too far north. Compute the set-off necessary to locate each section corner.
12. It is desirable to have the rows of apple-trees in an orchard parallel to a fence at one of the sides. Devise a practical method by which the trees may be so located in rows, twenty feet apart each way, and at right angles to each other.
13. How many rods of tile will it take to tile a forty, with laterals four rods apart, if they run parallel and diagonally? If they run at right angles to one side?
14. Devise a plan by which the meridian may be staked on the ground, by reference to the north star.
15. Line AB is N 15 degrees 30 min. E
    Line AC is N 87 degrees 14 min. E
    Line AD is S 2 degrees 0 min. W
    Line AE is S 24 degrees 2 min. W
    Line AF is S 67 degrees 30 min. W
    Find the value of angles BAC, BAD, CAE, CAF, BAF, and FAD.
16. If the bearings given in Problem 15 were magnetic, what are the real bearings, the declination being 5° E.?
17. Compute the area of (1) Sec. 6, T. 16, R. 4 W. shown in the diagram; (2) Sec. 6, T. 16, R. 3 W.; (3) Sec. 5, T. 16, R. 3 W.; (4) Sec. 6, T. 15, R. 3 W.; (5) Sec. 5, T. 15, R. 3 W.
18. With 53.48 for the elevation of the turning-point, the new H. I. is found to be 57.64 and the new turning-point is 54.72. What must the F. S. and B. S. readings have been?
19. What readings would there be at each station of Line II (Fig. 15) if the H. I. is 56.27?
20. Suppose that two systems of levels had been run, each having a different datum. According to the second datum, the B. M. = 34.76. What will be the elevation of each station on Line II, according to this datum?

Part Two.

NOTES ON DRAINAGE.

CHAPTER IX.

MOISTURE AND AGRICULTURE.

65. The Necessity of Water.—Water is so common in its occurrence that its importance is often overlooked. All vegetation is dependent upon it for the solution of the soluble plant food in the soil, and for its circulation through the vegetable structure. Then also transpiration of water, the excess of which evaporates from the leaf surfaces, cools the plants and keeps them from burning up in the scorching rays of the summer sun. The amount of water actually required for a particular crop is known as the *duty of water* for that crop. This amount includes both that which is used by the plant directly and that which is lost by evaporation and seepage from the soil. These losses vary greatly in different parts of the United States.

66. Variation in the Water Supply.—In some parts of our country the duty of water far exceeds the rainfall. The average duty found on seven large main canals in operation in the semi-arid states of the Southwest was 5.47 feet, while the average rainfall was barely more than as many inches. The water which entered the laterals from these main ditches averaged 2.45 acre-feet for the land irrigated, and the water which was available to growing crops after the wasteful losses from these laterals were eliminated was 1.34 acre-feet. Thus the necessity of supplying water artificially in those localities is very evident. This is known as *irrigation* and does not come within the scope of this work.

But, on the other hand, there are localities where the rainfall greatly exceeds the duty of water. In the neighborhood of Puget Sound the annual rainfall often reaches 100 inches. A map of the U. S. showing the rainfall may be found in the bound volumes of the Monthly Weather Reports published by the government. In addition to the actual rainfall, some areas receive surface water from other land in the same basin. In all of these places the removal of surplus water must be accomplished either by natural or artificial means. This process is known as *drainage,* and the problem it presents is a vital one to a large portion of the Mississippi Valley.

67. Causes of Rainfall.—Since the matter of drainage is very dependent upon rainfall conditions, a brief study of the causes and distribution of rainfall may be properly taken up here.

Practically the only principle upon which authorities agree as to the cause of rain is that a sudden cooling of the air below the dew point is necessary. When the air is cooled a portion of the vapor is thus changed to the liquid state and the particles thus formed may float away with the wind or they may increase in size sufficiently to be drawn to the ground by virtue of gravity. Whether the condensation results simply in a cloudy effect, or whether rain actually falls, depends upon the magnitude of the temperature changes taking place in the air. The precise manner in which the air is cooled is not clearly understood. It is quite definitely established, however, that air cools by expansion as it rises. Since each "Low" barometer area as indicated on our daily weather maps has at its center a rising column of air, this is perhaps the most common cause of rain, and the reason why each "Low" area as it travels across the continent is usually accompanied by rain.

68. Fluctuations in Rainfall.—The question as to whether the rainfall, either the general or that in particular localities, is increasing or diminishing in recent years has been discussed at length, but to no definite conclusion. With the data at hand there is not sufficient evidence of a systematic fluctuation in the rainfall. The occurrence of more excessive floods at irregular intervals than formerly, is due to the clearing of the land (**73.**).

69. The Three Annual Periods.—The majority of writers on rainfall have divided its records into three periods—those of *storage, growing* and *replenishing.* The water year is considered as beginning with December 1st, and the storage period extends from that time until June 1st. During this period the absorption and evaporation due to plants is relatively small, and a large part of the rainfall appears in the streams. The growing period extends from June 1 to September 1, and includes the period of vegetative growth when evaporation and absorption by plants is most noticeable. During this period less than one-tenth of the rainfall is found in the streams as run-off. Ground water tends to become lower during this period, unless the rainfall is much larger than the average. During the remainder of the water year, the replenishing period, there is less vegetative growth, consequently less water used by the plants, and as the soil resumes its normal condition and becomes more thoroughly saturated, the run-off in the streams also increases slightly over that for the preceding period. Of course, the dates marking the beginning and the end of each year vary from year to year, but after considerable study the foregoing dates have been accepted as fairly representative of the average conditions.

CHAPTER X.

DISPOSAL OF THE RAINFALL.

70. Methods of Disposal.—The water which falls as rain is disposed of in one of four ways. It either evaporates directly, is transpired by plants, percolates downward to join the great body of ground water, or escapes as surface run-off.

71. Evaporation and Transpiration.—The rate of evaporation depends upon the degree of saturation of the air in contact with the evaporating surface. If the air is kept in motion, dry unsaturated air is continually being brought into such contact. Thus also the rate of evaporation increases with the size of the evaporating surface. For this reason, when the water table is very near the surface of the soil evaporation is faster than it would be from an equal water surface.

The fact that growing plants transpire no small amount of moisture is proven by putting a bell-jar over the plant. The interior of the jar will soon be covered by a collection of vapor particles which have been exuded by the plant.

72. Percolation.—The water which percolates downward is a quantity which is very difficult to measure and one subject to great variation. When obstacles are offered to the three other means of disposal, a great deal of water is disposed of in this way. Vegetation or a layer of leaves lessen the run-off and increase the percolation. The amount of water thus held has a very marked effect upon the flow of springs. Springs at the foot of slopes, at which there was a strong flow when the slope was covered with forest, have been known to dry up when the slope was cleared. An interesting feature of the movement of this spring water is that it is for awhile held in the soil by the percolation process and later it escapes through crevices in the rock layers and flows away as surface run-off. Springs are always found at the top of an impervious layer. The water moves down to the layer by *percolation;* the lateral movement by which it moves more or less horizontally is called *seepage.* By those two movements the water table in the soil is continually changing in its form. During a period of excessive rainfall the water table is relatively high and conforms rather closely to the topography of the overlying land surface. During a continued dry period, the ground water of the hills sweep slowly into that of the valleys and the water table becomes more nearly horizontal. The effect of such a dry period upon the wells in uplands is thus more marked than that upon those of the valleys. This variation with rainfall in the height of water in wells and the flow from springs, shows that a considerable portion of the rainfall moves downward into the ground.

73. Surface Run-off.—The surface run-off varies inversely as the percolataion. It includes both the flood flow of streams and the dry weather flow, the latter being fed chiefly by springs. It varies with the size, slope and condition of surface, of the catchment basin. However, the run-off from the same basin varies greatly from year to year. Here, also, attention must be called to the fact that the drainage engineer is more concerned with the maximum flood flow that with the total run-off for the year. If a ditch is large enough to take care of the former, it certainly will accommodate the latter. Mr. C. G. Elliott, Drainage Expert for the Department at Washington, finds that a ditch should be large enough to remove ¾ of an inch of water from the entire area in 24 hours where the area is smaller than 3,000 acres; ½ inch for areas between 3,000 and 10,000 acres; and ¼ of an inch for areas greater in size than 10,000 acres. The reason for a decrease in the depth to be removed as the size of the drainage basin increases is that in the large area the water has farther to move on the surface before it reaches the ditch. With the surface obstacles to flow, the flow will be slower, and excessive demands will not be made upon the ditch. These amounts however, should be increased where the slope is greater than 3 feet to the mile.

CHAPTER XI.

THE MOVEMENTS OF UNDERGROUND WATER.

74. Three Kinds of Soil Moisture.—A definition of the three kinds of soil water is not out of place in this connection. *Hygroscopic water* is that portion which is found in fine globules on the surface of soil grains that are apparently dusty and dry. *Capillary water* is that which keeps moist the soil lying underneath the dust mulch at the surface. It exists as a continuous film around the soil grains. The *gravitational water* is that which can not be held in the soil by capillarity, but which, when given an opportunity, will be drawn downward by gravity (72).

The hygroscopic moisture of the soil and its movements, if any, is of little importance in agriculture. On the contrary, the control of capillary moisture within the soil is one of the vital problems in successful soil management. However, mention is made of it here simply because of its relataion to the gravitational water with which we deal in all matters relating to drainage.

75. Water-Holding Capacity of Soils.—The amount of capillary water that a soil will hold is known as its water-holding capacity. This is greater for soils of fine grains than for those of coarse grains, because of the greater surface of the former. Humus and other organic matter increase the water-holding capacity. A high temperature tends to decrease it.

Whenever the water-holding capacity of a soil is exceeded, a flow results, due to gravity. Other things being equal, water will move farther in an *open* soil than in a *retentive* one. The degree of fineness into which the pore-space is divided is a greater factor in determining the retentiveness of a soil, that the extent of the pore-space. Clay has a greater pore-space than sand but it is more finely divided.

76. Effect of Mechanical Composition. — The amounts of sand, silt and clay of which a soil is composed is determined by a mechanical analysis. This is usually accomplished by allowing a sample of the soil to settle in a column of standing water, the larger particles, of course, settling first. Such an analysis, however, does not always furnish an index for the rate at which the water will move through the soil. There are sub-soils in which the sand content is 50 per cent. but whose grains are angular and upon compacting, wedge together so as to form almost a solid mass. Other soils, relatively high in sand content, have just enough silt and clay particles to act as a cement between the sand grains, thus forming a "hard pan" almost impervious to water.

77. Flocculation of Clay.—Clay, although of exceedingly fine grains, has the property of *flocculation*. By this is meant the conversion of the clay particles into clusters resembling a sand grain in size. When the clusters are broken down the soil is said to be *puddled.* Lime tends to flocculate clay while some other salts tend to puddle it. Sodium carbonate (black alkali) is frequently applied to the soil in the foundation of reservoir dams, to make them impervious to water. For the above reasons King's method of determining the rate at which air can be drawn through the soil is perhaps the best means we have of testing the openness or retentiveness of soils.

78. Other Factors Influencing Underground Flow. In Table VI it will be noticed that the porosity, temperature and pressure gradient are indicated as being the factors determining flow. With a pore-space equal to 40 per cent the flow would be twice as great. For practical purposes the flow is assumed to be directly proportional to the pressure gradient, but experiments tend to show that the flow increases a trifle more rapidly than the pressure.

TABLE VI.

Velocity of ground water in materials of different grades, pressure gradient 10 feet per mile, porosity 32 per cent and temperature 50° F.—From Slichter.

Material.	Feet per year.
Fine sand, 0 2 mm diameter	52.8
Medium sand, 0.4 mm diameter	216.0
Coarse sand, 0.8 mm diameter	845.0
Fine gravel, 2.0 mm diameter	5,386.0

79. Zones of Flow.—With reference to their motions, underground waters are divided by Slichter into three zones: (1) the unsaturated zone; (2) the surface zone of flow; and (3) the deeper zones of flow.

The gravitational water in the unsaturated zone moves vertically downward to the saturated sheet below. The surface zone of flow extends from the top of the water table to the first impervious rock layer. The deeper zones of flow are below the impervious layer at whose upper end the water enters. Here the direction of flow does not conform with the surface topography as it does in the surface zone. The direction is determined by the tilt of the obstructing layers. Upon drilling through the impervious layer, where the head is sufficient, an artesian well results.

80. Effects of Hardpan.—A sub-stratum of clay acts like a basin and unless there is enough slope to admit of surface drainage, the flat area becomes a marsh. Instances are common where the clay is underlaid with gravel belonging to the unsaturated zone. In such cases, drilling into the gravel will allow the water held above to escape. The feasibility of this method of draining will depend upon the elevation of the lower water table which in turn may be ascertained from wells which have been drilled in the surrounding upland.

CHAPTER XII.

NATURAL SURFACE DRAINAGE.

The natural surface drainage which is found at present has been continually going through a process of change and development. This movement has been so closely related to and dependent upon the structure of the rock layers of the earth, that a brief mention of the latter is here made.

81. The Rock Layers.—The upper Mississippi Valley is supposed to be underlaid with a layer of rock of unknown thickness, which may be regarded as an undisturbed portion of the original crust of the earth. The granite rocks of north central Wisconsin belong to this layer and mark the location of the Wisconsin island which alone rose above the surface of the surrounding water. As the process of erosion began, sedimentary layers were formed in the bottom of the sea. The lowermost of these of which there is an outcrop in Wisconsin is the Potsdam sandstone. It consists of broken quartz grains of the decomposed granites and allied rocks. Being very porous and of sufficient slope, it is the vein of rock that supplies most of our artesian wells with water. This layer is sometimes 1,000 feet in thickness.

Lying upon the Potsdam layer and likewise owing their origin to the Archean islands, are found in the following order: the Lower Magnesian Limestone, the St. Peter's Sandstone, the Trenton Limestone, the Hudson River Shale, and the Niagara Limestone. Outcrops of all of these layers may be found on the side of the Blue Mounds slope, about twenty miles west of Madison.

82. Action of Ice and Water.—As these several layers rose above the sea, the running water cut out narrow valleys and left abrupt, bold hills between. Having been formed by running water, the drainage in these valleys was good. The valleys were becoming wider, and the projecting hill-tops, less bold. In the southwestern part of Wisconsin where there are well worn valleys with ramifications becoming narrow, in other words newer, as the head is reached, we have an example of what the result is where this process of erosion is allowed to go on without interruption. But the other three-fourths of Wisconsin was overrun with glaciers. These large masses of ice came down from the north, pushing moraines of rock and soil ahead of them. They ground off the hills and filled up the valleys. When the glaciers receded the entire topography had been changed. The dams placed across the valleys made lakes of the areas above. The high water that resulted from the melting of the glaciers easily made new channels. Lake Michigan still emptied into the Mississippi, though by a different route than formerly. Lake Superior emptied into the Mississippi through the present St. Croix Valley. But, when the ice melted around the northern extremity of Lake

Michigan, the channels scooped out by the glaciers to the eastward gave this water an outlet in that direction, which it has kept ever since. The course of the Mississippi river was also changed during the glacial perior. The sediment washed in by the glacial streams placed dams across the old valleys. In such places the course of the water was diverted to another valley. The rock ledges between these early valleys are what form the present numerous rapids and falls in the upper Mississippi.

83. Drainage Conditions at Present.—The effect of glacial action upon the drainage of the present is marked. In the glaciated portion of the state we find flat areas, sometimes old lake beds, with very imperfect natural drainage. Such areas are usually marshes and are very common in the southeastern and northern part of the state. In the southwestern part of the state where the water escapes through water-cut valleys the surface drainage is usually good. As the topography becomes older and more uniform with erosion, however, the streams become more sluggish and the tendency to inundate, perhaps, increases. On the glaciated portion the surface drainage is becoming better. The old lake beds are filling up with sediment, and the action of running water is wearing down the dams which formerly held the water back. The result is that this area also is gradually acquiring an erosion topography.

CHAPTER XIII.

LAND REQUIRING ARTIFICIAL DRAINAGE.

84. Three Classes of Land.—Generally speaking, there are three conditions which require drainage: first, land which is wet and marshy; second, land which has sufficient slope to afford good drainage, but which, on account of the large amount of vegetable matter or humus it contains, and of its impervious clay subsoil, does not have good under-drainage; and third, flat land along sluggish streams which, though normally free from excessive water, is at times subject to the overflow of the stream.

The lack of drainage in the first case is readily seen and understood but the importance of drainage in the second case is not generally recognized, although its benefits are as great as in the case of marshes. Land belonging to the third class may be inundated but once during the growing season, but that one flood is apt to be sufficient to impair the growth of the crop, if it be a cultivated one, as much as if it had been wet all the time.

It is safe to say that all land wherein the water table is within four feet of the surface of the soil during the growing season, can be materially benefitted by drainage.

85. Benefits of Drainage Enumerated.—Considered in detail the benefits of drainage are as follows:

(a) Allows cultivation of land not otherwise available for farming.
(b) Allows earlier working in the spring.
(c) Lessens the danger of spring frost.
(d) Less water is evaporated and hence there is less cooling by evaporation.
(e) Produces good ventilation and tilth in the soil.
(f) Increases the amount of water available to crops.
(g) Aids nitrification, retards dentrification.
(h) Lessens surface washing.
(i) Allows fields to be made more uniform in outline and hence worked to better advantage.
(j) Prevents the accumulation of injurious salts in the soil.

86. To What Extent Is Drainage Warranted?—The above mentioned conditions are all essential to an ideal soil, but the actual profit that will attend draining should determine the extent to which it is warranted. A safe rule to follow is not to invest any money in drainage works which cannot be reasonably expected to yield a good income on the amount invested. As a matter of fact, however, drainage usually pays for itself in two years, so that the income from increased crops thereafter is a clear profit, and aside from this the market value of the land is raised more than enough to cover the original cost of the tile. Some specific cases are cited in Bulletin 138 (Wis.).

87. The Market Value of Surrounding Upland a Factor.—The importance of drainage is becoming greater as the agricultural resources of the country are developed. The lands first occupied in a new country are always those which are readily broken and have good drainage. The poorly drained lands are used only as pasture and wild hay land; but as the surrounding upland becomes worth upwards of $100 per acre a different standard is made which determines whether or not this land can be drained with profit.

88. Wisconsin Conditions.—For more specific conclusions as to the extent to which land drainage may be practiced in Wisconsin, the student is referred to the summary on page 45 of Bulletin 146 (Wis.).

CHAPTER XIV.

METHODS OF ARTIFICIAL DRAINAGE.

89. Giving Gravity an Opportunity.—Any work that man can do to improve drainage conditions must be done by merely assisting in some way the force of gravity. This is accomplished by means of *open ditches* or covered conduits, such as *drain-tile.* The underlying principle is that water confined to a well defined compact channel meets with less resistance to flow than it would if forced to flow in a wide shallow sheet over the obstructed surface of the ground. The velocity will be greater in a straight channel from source to outlet than in a devious channel, because the same head through which gravity acts is distributed over a comparatively short distance, and the head per unit of distance is thereby increased. The straightened channel can be frequently made to have only one-fourth of the original length.

Winding, sluggish streams of this sort are usually found in marshy areas—the flatness of the land is what made the water course so devious originally, and open ditches are perhaps the best means of lowering the water table, and of preventing damage to crops in time of flood flow.

90. Details of Ditch Construction.—The size required in open ditches will be discussed in a later chapter (107). It will depend largely upon the size and character of the catchment basin. The form of the ditch must be made to vary with the soil. A ditch wholly in peat needs very little side slope; clay banks require a slope of 1 to 1; loamy soils 1½ to 1. Where a ditch dug in shallow peat extends down into the underlying sand, the peat banks will become undermined by the erosion of the sand. In all ditches the banks gradually become steeper at the top and less steep at the bottom.

The earth excavated forms the *waste bank.* The space between this and the ditch bank is called the *berm.* This should be equal to the depth of the ditch, or the weight of the waste banks will cause the sides of the ditch to give way. Frequent openings should be left in the waste bank to allow the surface water to enter the ditch. A waste bank presents an ugly appearance and should be levelled off and sodded over as soon as convenient.

91. Cost of Open Ditches.—The cost of excavation varies with conditions. Clear peat can be handled for five or six cents a cubic yard. Where some sand must also be removed the price is commonly eight cents. On small jobs the cost is relatively higher because of the expense of moving a large dredge—an expense so great that a dredge owner can hardly afford to take a job that amounts to less than $5,000. These dredges vary in weight from ten to ninety tons, with dippers from a half to three cubic yards. They are mounted on hulls or boats which require that the ditch be kept full of water either by beginning at the head and working down stream, or by beginning at the outlet and keeping a dam behind the dredge as progress is made up stream. There are no floating dredges made with hulls less in width than eight feet. Some of the larger ones are over a hundred feet long and thirty or forty feet wide. The majority of dredges are run by steam, but gasoline is fast coming into use because of the difficulty of hauling coal over the marshes.

The floating dredges are moved ahead by means of wire cables—one end fastened to a drum run by the engine and the other to a tree or other stationary object. Some of the dredges used in Wisconsin have a walking device which gives them their name. They are able to propel themselves over dry ground sometimes at the rate of a mile a day and are used with advantage on small ditches or laterals, while floating dredges would have to be torn down and hauled in pieces at a cost of no less than $2,000.

There are as yet, few machines that will dig a ditch as small as six feet deep or twelve feet wide at the top. On areas not exceeding a thousand acres, ditches of this size are about what are wanted, but at present they must be made by hand at a cost perhaps twice as great per cubic yard as that paid for dredging. For this reason all of the owners of wet land in the locality should be interested in drainage so that the project can be made large enough to attract the attention of a dredge owner. A greater area will be benefited at a lower relative cost.

92. Disadvantages of Open Ditches.—Open ditches have disadvantages as well as advantages. First, they are expensive. To make a ditch stand six feet deep, it must be at least twelve feet wide at the top. Second, they are not permanent. The sides gradually become steeper near the top and less steep near the bottom. Unless the velocity makes the ditch self cleaning it will slowly fill up. Vegetation is particularly detrimental. Third, they are in the way. This applies to both the ditch and the waste-banks. Fourth, they occupy too much land. And fifth, they carry away plant food in solution which would wholly or in part be held by the soil if the water, to escape, had to percolate down to tile.

93. Drainage of Peat Marshes.—It has been said that open ditches are the first step in the reclamation of swamp lands. They represent, perhaps, the extent to which wild peat lands can profitably be reclaimed at the present price of land. Here again the student is referred to pages 22–24 of Bul. 146 for a detailed plan of open-ditch drainage for a typical peat area.

94. Ditches, the Essential Auxiliaries of Tile.—It will be seen later that open ditches are essential auxiliaries of tile. Unless there is a ravine conveniently located, an open ditch is all that will afford an outlet for the tile.

There is another way in which open ditches and tile work hand in hand. No matter how well the tile do the work expected of them, there are apt to be downpours of rain that should be removed with more rapidity than is possible where the water must percolate down to the tile. We need the tile to effect deep drainage and the open ditches to effect quick drainage.

A depression with gradually sloping sides, perhaps not more than two feet deep, yet open to the outlet, will at least prevent water from standing on the surface. Where such ditches are ordinarily kept dry by the tile, they sod over, present a neat appearance and are not in the way. They can be dug with team and scraper, but the earth excavated should be hauled some distance away. Not infrequently there are holes that can be filled advantageously with this earth. It would be cheaper where a large tile main is also laid to fill the trench only partly full, and to leave the rest for a depression to carry away extraordinary surface water, but this is not a safe thing to do unless there is three feet of earth still over the large tile. The running surface water is apt to unearth the tile and aside from this danger, with the ditch only partly filled, there is less protection from frost. It is best to have the open water-way a little at one side of the line of tile.

95. Furrows for Surface Drainage—Dykes.—On fields in regions of retentive clay soils it is profitable to make furrows with a plow after the grain is sown, as a provision for surface drainage. If the fields are laid out in long, narrow "lands" extending in the direction of greatest slope, the dead furrows will provide drainage. This is one of the cheapest and best methods of draining lands that are subject to the overflows of sluggish streams. Tile fail because the outlet is submerged when needed the most. Then also when the high water begins to ebb the surface water on the overflowed land moves down the shallow ditches before it could be expected to escape through tile which would have to be laid at a greater depth.

Such overflows may sometimes be prevented by means of dykes.

96. Early History of Tile Drainage.—We have records of the use of crude tile for drainage in France as far back as 1620. Land drainage was given a stimulus by the discoveries of Elkington in the years following 1763. He found that land could be drained by boring through the impervious sub-soil into the more open strata below. For his discoveries Parliament voted him £1,000 as a reward. Several experimenters followed him, each having a different opinion regarding tile drainage. Newspaper articles on the subject began to appear on this side of the Atlantic, and in 1838 John Johnston, "the father of tile drainage in America," imported some patterns from which horse shoe tile were made. They were laid on his farm near Geneva, New York, and proved very successful. Later the horse-shoe tile were provided with soles, and in 1858 the first circular tile were made.

97. Devices That Have Been Used.—Among the other materials that have been buried in trenches for underdraining, are V-shaped troughs inverted, brush, gravel and stone. Shoulder drains have been made by making the ditch become suddenly narrower near the bottom. Sods inverted on this shoulder keep the narrow trench below open for two or more years.

98. The Mole Plow.—The mole plow consists of a steel ball fastened at the end of a strong arm which is run at depths as great as three feet in clay subsoils. The continuous openings thus formed have been known to remain open for a number of years.

99. Cylindrical Tile are Best.—These and other schemes have been employed but the majority of American farmers prefer to follow the example set by the old Scotch farmer in New York nearly three quarters of a century ago, and circular tile burned from clay will without doubt be considered the best and eventually the cheapest method of underdrainage where an adequate outlet can be secured.

CHAPTER XV.

VELOCITY AND DISCHARGE.

100. Factors Determining Velocity.—Although the slope is primary in causing the flow, this flow is modified by a number of factors. A ditch in poor condition, overgrown with grass and otherwise irregular, will carry only about one-fourth as much water as a canal of the same size and slope, but faced with cement. A very little grass will decrease the flow by one-half. The form of the ditch is also an important factor. The sides and the bottom of the ditch touched by the water are known as the *wetted perimeter*. The resistance to flow decreases directly with this factor. Hence it is advisable to have the wetted perimeter as small as possible in comparison to the area of the cross section. The number of square feet in the cross section divided by the number linear feet in the wetted perimeter is called the ***hydraulic mean depth*** of the ditch, and the flow varies with it. The hydraulic radius, as the mean depth is called, is larger the more nearly the form of a square a ditch is. In the ditch whose form of cross section is that of a semi-circle the hydraulic radius reaches a maximum for that area. A ditch of this form would not be practical however, and ditches are usually made trapezoidal in form, as already described (90).

101. Determination of Discharge.—In computing the capacity of a ditch, there are two essential factors. The discharge is always equal to the product of the number of square feet in a cross section and the velocity in linear feet per second, this product always giving the discharge in cubic feet per second. It is comparatively easy to find the area of cross section of a ditch. The velocity must be determined by observations made with the use of a current meter or a float, or it may be computed by a formula which has been derived and proven by observations.

102. The Sub-Surface Float.—The sub-surface float is so weighted that it is carried along in a plane about six tenths of the distance from the top to the bottom. This has been found to represent the average velocity. The maximum velocity is usually found in a plane a short distance below the surface, usually about one tenth of the total depth. When there is a wind blowing down stream at a velocity exceeding that which the water would normally have, the maximum velocity will be at the surface.

103. The Current Meter.—The current meter is perhaps the most reliable instrument for velocity determinations. It consists of a water wheel immersed in water and has a "clicking" arrangement by means of which the revolutions of the wheel may be counted. The velocity at six tenths of the depth may either be assumed to be the average for the vertical column passing through that point, or the meter may be moved at a uniform rate from the top of the bottom and again back to the top. In either case the number of "clicks" and the number of seconds supply the data from which the velocity is determined by means of the rating curve of the particular instrument used.

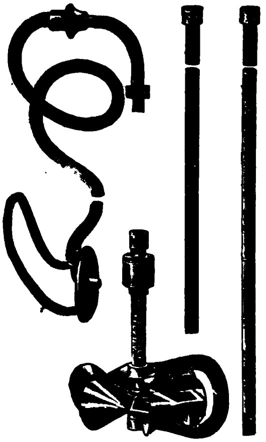

Fig. 18.—The current meter and attachments.

104. How To Use the Current Meter.—The first step in gauging a stream is to measure its depth at intervals of four feet across the stream, beginning at a point two feet from one side. These depths are assumed to be the average for the vertical section four feet wide of which each is the center respectively. The velocity found is the average velocity for the section and the product of the velocity and the area is its discharge. The sum of all the products is the total discharge of the stream.

105. Units of Measure.—The American unit of flow is the second-foot, or cubic feet per second. The discharge from pipes is sometimes given in gallons per minute. An old unit which grew out the necessities of frontier life in the West is the miner's inch. It is still used to some extent to measure water for irrigation, but it is not an absolute quantity. The most definite standard that has been adopted is: An aperture twelve inches high and twelve and three-fourths inches wide, through a one and one half inch plank, with the top opening six inches below the surface of the water, is said to discharge two hundred miner's inches. On this basis a miner's inch is about .025 second-feet.

For expressing quantities which imply a relation between the amount of water and the surface over which it is spread, the acre-inch is used. By this is meant the water required to cover an acre to the depth of one inch. An acre-inch in twenty-four hours is approximately the equivalent of .042 second-feet.

106. The Weir.—Another means of measuring the quantity of moving water is the weir. It consists of a sharp edge of known width over which the water runs and above which its height is measured. Some weirs are rectangular, but Cippoletti has devised one trapezoidal in form and with side slopes of 1 to 4. This eliminates the error of "end contraction" and the discharge is computed from the formula,

$$Q = 3.367\ LH.^{\frac{3}{2}}\ \text{second-feet}$$

where L and H are each expressed in feet. By making determinations at several different heads, it is possible to plot a curve which will show the discharge for all intervening heads. To be reliable, a weir must have:

(1) Horizontal crest.
(2) Plane of face normal to the line of flow.
(3) Thin edges.
(4) Head (H) measured some distance up stream.
(5) Length of crest (L) not less than 3H.
(6) Ends 2H from sides of canal.
(7) Crest 3H from bottom of canal.
(8) Free spill-way below the weir.

The most accurate results will be obtained when H is greater than 0.2 feet and less than 2.0 feet. Table VII may be found convenient for use.

TABLE VII.

Discharge of Cippoletti wiers in cu. ft. per sec. computed from formula $Q.=3.367\ LH^{\frac{3}{2}}$.

Depth of water on crest.	LENGTH OF SILL OF WEIR.				
	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.
½ inch	0.029	057	.086	.114	.143
1 inch	.081	.162	.243	.324	.405
1½ inch	.149	.297	.446	.595	.741
2 inch	.229	.458	.687	.916	1.145
2½ inch	.320	.640	.960	1.280	1.601
3 inch	.421	.842	1.262	1.683	2.104
4 inch	.648	1.296	1.944	2.592	3.240
5 inch	.905	1.811	2.716	3.822	4.527
6 inch	1.190	2 381	3.571	4.761	5.982
8 inch	....	3.665	5.498	7.330	9 163
10 inch	....	5.122	7.683	10.244	12.805
12 inch	....	6.733	10.100	13.467	16.833

107. Theoretical and Required Capacities.—In planning ditches for drainage purposes it is necessary to base the size on theoretical requirements and theoretical velocities. Here again it must be remembered that drainage for agricultural purposes demands a ditch equal in capacity to the maximum flood flow that may be reasonably expected. These amounts for marshes of small, medium and large sizes have been given (73) and those for marshes of intervening areas may be taken from the curve shown in Fig. 19.

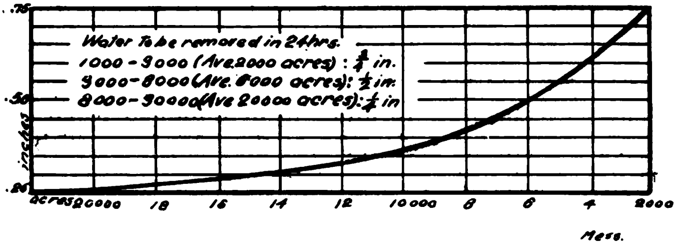

Fig. 19.—A curve showing how the theoretical run-off, in inches on the catchment basin, varies with the area.

108. Formula for Open Ditches.—The simplest formula for the flow of water in open ditches is that of Kutter,

$$V = C \sqrt{RS} \text{ feet per second}$$

where

C=coefficient depending on R and S.
R=the hydraulic radius.
and S=the sine of the gradient angle.
=fall÷distance

The coefficient C varies with R and to a slight extent with S, but for preliminary estimates of velocity the latter variation may be disregarded and C may be taken from the curve shown in Fig. 20, where it varies only with the value of R.

The size of ditch required for any area may be found as follows: Reduce the theoretical requirement taken for the given area from Fig. 19, to cubic feet per second. Then choose a design for a ditch that you think is approximately of the right size. By the formula find its discharge in cubic feet per second. If this discharge exceeds that which is required, choose a smaller ditch and keep on choosing and comparing until the desired ditch has been designed.

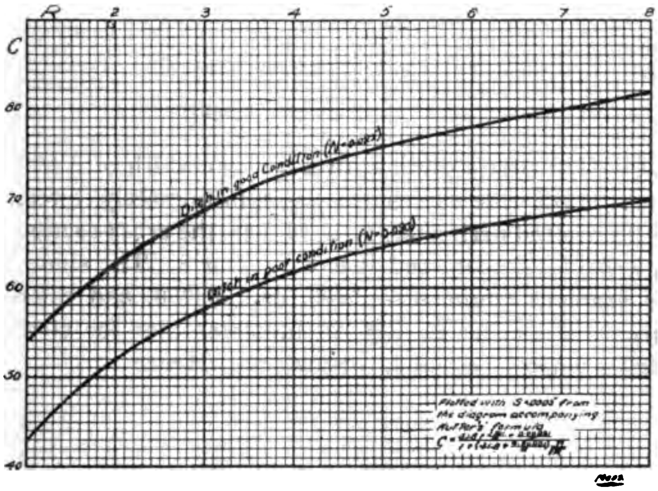

Fig. 20.—A curve showing how C varies with R in the formula $V = C\sqrt{RS}$ where S remains a constant at .0005. The curve is approximately correct for all values of S up to .001. This limit includes practically all of the ditches operating in Wisconsin at present.

Problem: How wide will a clean ditch dug 7 feet deep with side slopes of 1:1 and a fall of 4 feet to the mile have to be to remove the probable flow from an area of 12,000 acres, one-half of which is comparatively flat, and whose other half has a slope of about 10 feet or more to the mile, the water in the ditch to run at a depth of 5 feet?

Solution: That portion of the area which has a slope of 10 feet to the mile or greater will have to be multiplied by two before it is brought to a comparable basis. This would make the area drained be the equivalent of 18,000 comparatively flat acres. Reference to the run-off curve in Fig. 19 indicates that 0.26 inches should be removed in 24 hours.

$$\begin{aligned} 026 \times 18{,}000 &= 4680 \text{ acre-inches } (105). \\ 4680 \times 042 \ (105) &= 196 \text{ sec.-ft.} \\ &= \text{required capacity.} \end{aligned}$$

Take for trial a ditch with a bottom width of 8 feet. Each of the side slopes will be approximately 7 feet, so the wetted perimeter, P, is 22 feet, the cross-section, A, is 65 square feet and R is 65÷22 or 3. The sine of the gradient angle is 4÷5280, or .000758, and reference to the curve in Fig. 20 indicates that for clean ditches when R. equal 3, C equals 69. Hence

$$\begin{aligned} V &= 69 \sqrt{3 \times .000758} \\ &= 3.29 \text{ feet per second.} \\ \text{But } Q &= AV \\ &= 3.29 \times 65 = 214 \text{ sec. ft.} \end{aligned}$$

This is somewhat in excess of the required capacity so let us try a ditch 7 feet wide at the bottom.

$$\begin{aligned} \text{Here } A &= 60 \\ P &= 21 \end{aligned}$$

and R, S and C, hence V remain the same. Then AV=197 sec.-ft., which is only a trifle in excess of the required capacity, and hence 7 feet is the bottom width we will choose for the proposed ditch. At the top of the water it will be 17 feet wide and the top of the excavation will be 21 feet in width.

109. Flow in Pipes.—The simplest formula for the flow of water in pipes is perhaps

$$V = 50 \sqrt{DS} \text{ feet per second}$$

which is a modification of Beardmore's formula. Here

D=diameter of the pipe in feet.

S=sine of the gradient angle.

Problem: Find the discharge of a three-inch pipe, having a fall of 0.3 per 100 feet. Here D is 0.25 feet and S is 0.3 divided by 100 or .003.

$$\text{Then } DS = .00075 \text{ and } \sqrt{DS} = .0273$$
$$.0273 \times 50 = 1.365 \text{ (Velocity).}$$

The cross-section of the pipe is .04909 square feet and 1.365x.04909=.067 sec.-ft. (discharge).

There is more resistance to flow in tile than in smooth pipes and Table VIII taken from Bulletin 187 of the U. S. Department of Agriculture by Elliott may prove a valuable guide.

TABLE VIII.

Areas from which one-fourth inch of water will be removed in twenty-four hours by outlet tile drains of different diameters and different lengths with different grades.*

Diameter of tile in inches.	Grade per 100 feet in decimals of a foot (with approximate equivalents in inches).							
	0.04 ($\frac{1}{2}$ in.).		0.05 ($\frac{5}{8}$ in.).		0.08 (1 in.).		0.10 ($1\frac{3}{16}$ in.).	
	Length of drain in feet.							
	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.
	Acres of land drained.							
5	17.3	13.5	17.7	14.0	19.1	15.7	19.8	16.7
6	27.3	21.4	28.0	22.2	29.9	24.8	31.2	26.4
7	39.9	31.4	41.1	32.7	44.1	36.4	45.9	38.7
8	55.7	43.7	57.3	45.6	61.4	50.7	64.0	53.9
9	74.7	58.8	76.5	61.2	82.2	68.1	85.6	72.3
10	96.9	76.3	99.5	79.5	106.7	88.5	111.2	94.0
12	152.2	119.9	156.1	124.9	167.7	139.3	174.8	147.9
14	222.8	175.9	228.7	183.7	245.3	204.3	256.1	217.4
16	310.2	245.0	317.8	255.9	341.4	284.6	355.4	302.5
18	414.4	328.7	424.9	342.5	456.4	381.3	475.7	405.5
20	537.6	426.9	551.6	444.9	591.5	495.8	616.4	526.7

*This table was computed from the formulas for determining the size for tile drains given in Elliott's Engineering for Land Drainage, which are:

$$(1)\quad v=48\sqrt{\frac{d(f+\frac{1}{2}k)}{l+54d}}$$

$$(2)\quad Q=av$$

$$(3)\quad A=\frac{Q}{.0105}$$

Where v=velocity of flow in feet per second.
a=sectional area of tile in square feet.
d=diameter of tile in feet.
f=total fall in length of drain.
k=depth of drain in feet at upper end.
l=total length of drain in feet.
Q=discharge of drain in cubic feet per second.
A=acres drained.
Constant 0.0105=quantity of water to be removed from 1 acre in 1 second of time.

Computations are made for two assumed lengths of drain—1,000 feet and 2,000 feet. $\frac{1}{2}k$ is 1.5 feet, that is one-half of depth of drain where the soil is open and saturated with water, under which conditions the drain will discharge its maximum quantity. Where the soil is close no additional head will be added by the free water of the soil, so that the factor $\frac{1}{2}k$ should be omitted in computations. Three feet of soil above the top of the drain has been assumed. It will be readily seen that the grade, length of drain, and openness of soil are important factors in the capacity of a tile drain for discharging soil water.

Table VIII—Continued.

Diameter of tile in inches.	Grade per 100 feet in decimals of a foot (with approximate equivalents in inches.)							
	0.12 (1½ in.).		0 16 (2 in.).		0.20 (⅜ in).		0.25 (3 in.).	
	Length of drain in feet.							
	1,000.	2,000.	1,000.	2,000	1,000.	2,000.	1,000.	2,000.
	Acres of land drained.							
5	20.6	17.6	22.1	19.4	23.5	20.9	25.1	22.7
6	32.5	27.8	34.8	30.5	37.0	33.0	39.6	35.9
7	47.7	40.8	51.1	44.8	54.3	48.5	58.0	52.8
8	66.5	57.0	71.2	62.6	75.6	67.7	80.9	73.6
9	89.1	76.3	95.3	83.8	101.4	90.7	108.4	98.6
10	115 6	99 2	123.9	108.9	131 6	117.9	140.6	128.1
12	181.7	156.2	194.6	171.6	206.8	185.6	221.1	201.8
14	265.8	229.7	284.9	251.7	302.5	272.2	323.5	296.1
16	369.5	319 7	396.3	350.4	420.6	379.1	449.9	412.2
18	494.4	428.1	529 1	470.1	562.2	508.1	601.8	552.5
20	640.4	556.6	686.3	610.5	729.2	660.3	780.0	718.2

Diameter of tile in inches.	Grade per 100 feet in decimals of a foot (with approximate equivalents in inches).							
	0.30 (3⅝ in.)		0.40 (4⅝ in.).		0.50 (6 in.).		0.75 (9 in.).	
	Length of drain in feet.							
	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.
	Acres of land drained.							
5	26.7	24.5	29.5	27.5	32 0	30.3	37.7	36.3
6	42.0	38.6	46.4	43.5	50.5	47.8	59.4	57.3
7	61.6	56.7	68.2	63.8	74.0	70.1	87.1	84.1
8	85.8	79.0	95.0	89.1	103.3	98.0	121.4	117.3
9	114.9	106.0	127.0	119.4	138.1	131.3	162.6	157.1
10	149.3	137 6	165.2	155.3	179.2	170.5	211.1	204.4
12	234.5	216.9	259 2	244.1	281.8	268.6	331.8	321.7
14	343.5	318.1	379.7	358.2	412.9	393.9	485.8	472.1
16	477.4	442.9	527.8	498.4	573.7	548.8	675 2	657.3
18	638.1	592.7	705.2	668 0	767.4	735.1	902 3	880.5
20	826.9	771.1	914.7	867.8	994.5	954.6	1,170.1	1,144.1

CHAPTER XVI.

THE DISTRIBUTION OF BENEFITS.

110. Fundamental Differences.—In the successful operation of our drainage laws the principle so fundamental to all forms of American liberty and justice—"Equal rights to all, special favors to none" must recognize the fact that no two areas are situated quite alike, and that this difference should appear in the form of dollars and cents upon the assessment roll. Every land owner should be content to have his drainage tax based, first upon the extent of benefit actually rendered by the work, and second upon the ease with which that benefit is effected. The land situated a half a mile away from the ditch should not be taxed as high as that which is nearer, and the land which is reached by a ditch only by blasting through rock should be taxed higher than that which may be reached with ease.

111. Rights Conferred by Ownership.—This basis implies a due consideration of the rights conferred to a land owner by his title of ownership. When a man buys a piece of land he buys with it all of the advantages of natural drainage pertaining to it. If it contains natural channels which will facilitate artificial drainage, or if it is so situated that there is but little

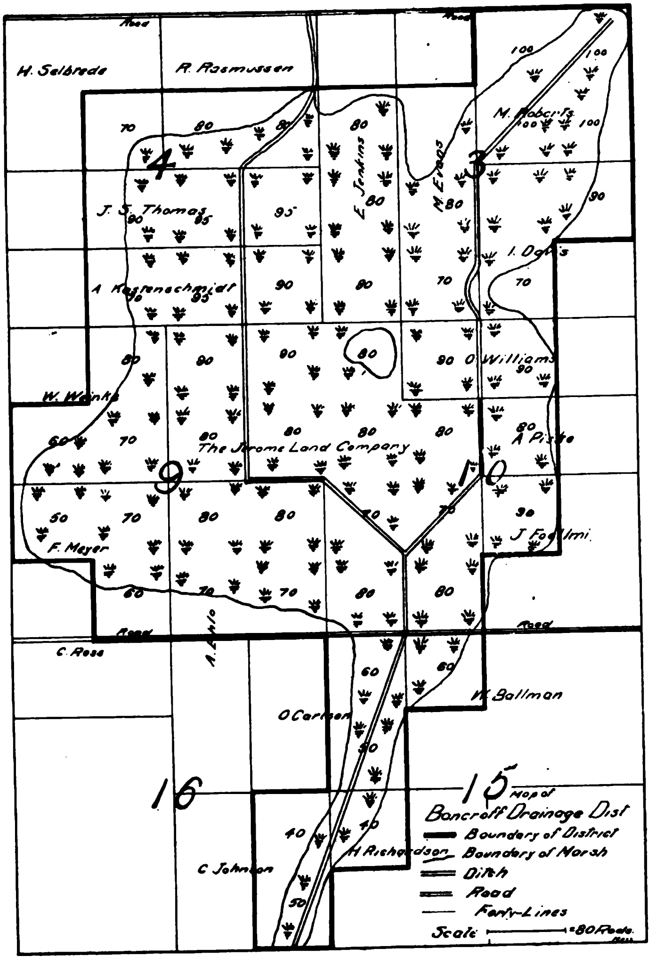

Fig. 21.—Map of a drainage district.

run-off from the surrounding upland to contend with, so much the better for the land owner—it is his good fortune, although in theory, at least, he had to pay more for his land in the first place for that very reason. The same is true of any natural slope which the land may have, or of any favorable condition found in the subsoil—all of these factors must be considered when a tax is levied for more complete drainage. This principle, however is like a two edged sword—it cuts both ways, and the land which has no slope, no natural outlet, and no protection from the run-off from a large area, must be taxed accordingly. This is not an injustice because, in theory again, the owner paid just that much less for his land in the first place. With these principles in mind let us apply them to the conditions represented in Fig. 21.

112. A Scheme for Rating Assessments.—The ditch shown in the figure is designed to have a fall of three feet to the mile. The pocket extending into Sec. 3 is the wettest part of the whole area, its natural outlet being obstructed by a gentile rise in the E½ S. W. ¼ of Sec. 3. This land being benefitted the most and requiring so much ditch in order to be reached at all is rated at 100. The N. W. ¼ S. W. ¼ Sec. 9 is rated at 50 because of the relatively poor drainage received by it due to its great distance from the ditch. The wet portion of the S. W. ¼ Sec. 4 is rated low because of the fair drainage that it already has. The N. ½ S. W. ¼ Sec. 10 is rated lower because the ditch damages it somewhat by running diagonally through each forty. The land near the outlet is rated low because it is manifestly unfair to make those owners pay for that portion of the ditch which lies above them.

113. The Flood Flow at the Outlet of the Ditch.—The contention is often made by landowners near the outlet of a district, that the extension of the ditch above them will bring down more water upon them, in time of flood, and to their damage. This contention, however, is groundless, because experience shows that when the land above is drained it acts like a sponge when a down-pour of rain does occur and allows actually less water to flood the land below than it would if the ground were previously saturated as it was before the artificial drainage was effected.

114. Benefit to Highways.—The town is assessed $200 for benefits done to the highways on the north line of Sections 15 and 3. Care should be taken in levying assessments against towns however lest the ill-will created among the non-interested tax-payers seriously interfere with the smooth-working of the district organization.

115. The Unit of Taxation.—It will be noticed that some high land is included within the boundary of the drainage district. The affected land owners need have no apprehension of this however because only those acres which are benefited are taxed. The number of acres on a forty multipled by the rate gives the number of units of taxation against the land, one unit being the tax on one acre rated at 1. This plan was originally.presented by Elliott in his "Engineering for Land Drainage" but an attempt is made here to bring out some additional features.

116. Odd Corners and "Islands."—A portion of the S. W. ¼ S. W. ¼ Sec. 9 is wet but is not included in the drainage district because it would mean that another landowner would have to be dealt with, and the expense of doing this is sometimes more than the tax which might be expected for the small benefit conferred. The "island" of high land shown in the N. E. ¼ N. W. ¼ Sec. 10 is assessed just the same as if it were all swamp land because a small tract thus isolated is almost worthless until access to it is gained by draining the surrounding land.

117. The Assessment Roll.—On the basis of these considerations the accompanying assessment roll has been prepared.

TABLE IX.

The assessment roll for the Bancroft Drainage District.

ASSESSMENT ROLL.

Amount to be levied, $8,000.

Owner.	Description.	Acres benefited.	Rating.	Units.	Total units.	Assessment.
H. Selbrede......	SE ¼ NW ¼ Sec 4	8	70	560	560	$ 34 64
R. Rassmussen...	SW ¼ NE ¼ Sec 4	16	90	1,440	3,840	237 84
"	SE ¼ NE ¼ Sec 4	30	80	2,400		
J. Thomas	NE ¼ SW ¼ Sec 4	20	90	1,800	9,400	580 95
"	NW ¼ SE ¼ Sec 4	40	95	3,800		
"	NE ¼ SE ¼ Sec 4	40	95	3,800		
A. Kastenschmidt.	SE ¼ SW ¼ Sec 4	20	70	1,400	8,600	531 51
"	SW ¼ SE ¼ Sec 4	40	90	3,600		
"	SE ¼ SE ¼ Sec 4	40	90	3,600		
E. Jenkins	SW ¼ NW ¼ Sec 3	34	80	2,720	9,120	563 65
"	NW ¼ SW ¼ Sec 3	40	80	3,200		
"	SW ¼ SW ¼ Sec 3	40	80	3,200		
M. Evans	SE ¼ NW ¼ Sec 3	17	100	1,700	7,540	466 00
"	NE ¼ SW ¼ Sec 3	38	80	3,040		
"	SE ¼ SW ¼ Sec 3	40	70	2,800		
M. Roberts......	NW ¼ NE ¼ Sec 3	9	100	900	10,800	667 48
"	NE ¼ NE ¼ Sec 3	33	100	3,300		
"	SW ¼ NE ¼ Sec 3	40	100	4,000		
"	SE ¼ NE ¼ Sec 3	26	100	2,600		

TABLE IX—Continued.

ASSESSMENT ROLL—Continued.

Amount to be levied, $8,000.

Owner.	Description.	Acres benefited.	Rating.	Units	Total units.	Assessment.
I. Davis...........	NW ¼ SE ¼ Sec 3	40	100	4,000	6,480	400 49
"	NE ¼ SE ¼ Sec 3	12	90	1,080		
"	SW ¼ SE ¼ Sec 3	20	70	1,400		
O. Williams......	NE ¼ NW ¼ Sec 10	40	90	3,600	6,570	406,06
"	NW ¼ NE ¼ Sec 10	33	90	2,970		
A. Piske..........	SW ¼ NE ¼ Sec 10	34	80	2,720	2,720	168 13
J. Foellmi........	NW ¼ SE ¼ Sec 10	32	80	2,560	2,560	158 24
T. Jerome Land Co	NW ¼ NW ¼ Sec 10	40	80	3,200	35,200	2,175 40
"	SW ¼ NW ¼ Sec 10	40	80	3,200		
"	SE ¼ NW ¼ Sec 10	40	80	3,200		
"	NW ¼ SW ¼ Sec 10	40	70	2,800		
"	NE ¼ SW ¼ Sec 10	40	70	2,800		
"	SW ¼ SW ¼ Sec 10	40	80	3,200		
"	SE ¼ SW ¼ Sec 10	40	80	3,200		
"	NW ¼ NE ¼ Sec 9	40	90	3,600		
"	NE ¼ NE ¼ Sec 9	40	90	3,600		
"	SW ¼ NE ¼ Sec 9	40	80	3,200		
"	SE ¼ NE ¼ Sec 9	40	80	3,200		
W. Weinke........	NE ¼ NW ¼ Sec 9	23	80	1,840	5,400	333 75
"	SW ¼ NW ¼ Sec 9	15	60	900		
"	SE ¼ NW ¼ Sec 9	38	70	2,660		
F. Meyer..........	NW ¼ SW ¼ Sec 9	35	50	1,750	5,450	336 84
"	NE ¼ SW ¼ Sec 9	40	70	2,800		
"	SE ¼ SW ¼ Sec 9	15	60	900		
A. Elho............	NW ¼ SE ¼ Sec 9	40	80	3,200	9,760	603 21
"	NE ¼ SE ¼ Sec 9	40	80	3,200		
"	SW ¼ SE ¼ Sec 9	20	70	1,400		
"	SE ¼ SE ¼ Sec 9	28	70	1,960		
O. Carlson........	NW ¼ NW ¼ Sec 15	30	60	1,800	3,300	203 97
"	SW ¼ NW ¼ Sec 15	30	50	1,500		
W. Ballman......	NE ¼ NW ¼ Sec 15	15	60	900	900	55 65
H. Richardson....	NW ¼ SW ¼ Sec 15	16	40	640	640	39 58
C. Johnson	NE ¼ SE ¼ Sec 16	5	40	200	600	37 11
"	SE ¼ SE ¼ Sec 16	10	40	400		
Totals.........	....	1,621	....	129,440	129,440	8,000 00

$\frac{8000}{129440}$=.0618=value of 1 unit.

The postponement of payment of the drainage tax for five years facilitates payment because the land should be producing something by that time.

In the above assessment roll, the tax varies from two and one half to five dollars an acre, which is about what the drainage of swamp land with open ditches has cost in the districts that have been organized in Wisconsin.

CHAPTER XVII.

GENERAL PRINCIPLES OF TILE DRAINAGE.

118. Three Kinds of Systems.—It seems best to divide tile drained areas into three classes on the basis of the kind of system by which each is drained. A gridiron system is shown in Bul. 138. Such systems are usually employed on flat marshes. The laterals are of uniform frequency and approximately at right angles to the main into which they discharge. On land with a gently rolling topography, tile are commonly laid only in the wet depressions. When two or more of these irregular, and usually curved laterals are joined by a main, just as branches unite in the trunk of a tree, we have what is known as a natural system which is also shown in Bul. 138. Between these two types, resembling each in some respects we have what may be termed a combination system.

119. Definition of Terms.—The upstream end of a line of tile is called the *head* as distinguished from the *outlet*. In the preceding as well as the following paragraphs the term *lateral* is used to designate a single line of tile receiving no branches. A *main* is a line of large tile that carries the discharge from a number of laterals. If a number of so-called smaller mains discharge into a larger one, the smaller ones are called *sub-mains*.

120. Double Main Systems.—Some gridiron systems have a double main for good reasons. Two mains are necessary where drainage water must be removed from two portions of a marsh separated by running stream. The only alternative is to lay a main tile under the stream-bed, large enough to meet requirements or to dig the ditch enough deeper to afford an outlet for the laterals of tile. In the one case, the main tile would have to be very large and it would be in danger of being unearthed by water which would at times run in the open ditch. In the other case a system of independent lines of tile would be the result. The chief fault with such a system is that each lateral has an independent outlet, and the work of protecting the outlets is thereby multiplied.

121. Kind of Tile Used.—Drain-tile may be burned from almost any clay from which brick can be made. Their inside diameters range from three inches to thirty inches. The two and a half inch tile are now a thing of the past. Twelve inch tile and the smaller sizes are a foot long. The shorter the tile the more joints and openings there are, through which the water may enter. The larger tiles are made in lengths as great as two and a half feet—the aim being to keep the length greater than the diameter. The thickness of the walls of the tile increase with the size.

Hard-burned, glazed or vitrified tile have recently come into use, and the movement in that direction will be greater as the price of vitrified tile is lowered by improved methods of manufacturing. Freezing does not injure them to the extent suffered by the porous tile when the water contained in the walls expands.

122. Size of Laterals.—In subsoils of clay where to insure efficient drainage the laterals must be four rods apart, three inch laterals are large enough to remove the water from the land coming within the range of each, if there is a fall of a tenth of a foot or more to the hundred feet. The slope is mentioned in this connection because of its very evident relation to the size of the tile, namely that the size of tile required to remove a definite quantity of water will decrease as the slope increases. The advisability of laying three inch tile with a gradient less than the above minimum is questionable. Larger tile are laid with half of this slope, and we have one instance on record where a six inch tile is absolutely level for six hundred feet. Here however the diameter of the tile itself may be said to constitute a head.

Laterals laid in a sandy sub-soil may be placed one hundred or more feet apart, because of the greater rapidity with which water seeps from a distance into the tile, and hence the greater area drained by each lateral. Such are the conditions that obtain in the peat marshes of the Wisconsin River valley.

Lines of tile in hollows must take care of the seepage from the surrounding upland, and hence, allowance must be made by laying larger tile than for ordinary laterals. The size of tile required depends upon the natural drainage of the hollow and the slope of its sides. References to specific cases are made in Bul. 138.

123. Size of Mains.—The size of mains should depend upon the size and character of the area drained. The table (**109**) by Elliott may be relied upon as a guide under ordinary conditions. In his "Engineering for Land Drainage," Eliott says that the removal of 1/4 of an inch of water in 24 hours meets the requirements of the average soil, subject to such changes as the special tract to be drained seems to demand.. That portion of the catchment basin with a slope of 10 feet to the mile should be doubled before the table is consulted. Greater slopes require greater factors based on the judgment of the engineer.

124. Depth.—Tile are laid at average depths varying from two and one half to four feet. Irregularities of topography necessitate laying them six or eight feet deep for short distances. With a proper outlet, tile lower the water table to the depth at which they are laid. Between the laterals the water tables rises at rates varying with the coarseness of the soil, from one foot to sixteen, to one foot in fifty. The gradient decreases with prolonged periods of dry weather.

Fig. 22 shows how deep laterals may be less frequent, and at the same time the deep drainage afforded gives the plant roots greater space through which to permeate.

125. Duration of Tile.—There is positive proof that tile, properly laid, will still be doing their work at the end of twenty, and even after forty years. How much longer than this they will last we do not know. It is true that in our northern regions tile will freeze nearly every winter on all but marsh areas unless they are laid more than three feet deep. But when freezing does occur, the movement of water into the tile practically ceases. With no zags containing standing water in the line of tile, the only water present to cause injury by expansion upon freezing, is that contained in the walls of the tile. With soft tile the damage from this source is small unless in the case of exposure to frequent, sudden changes in temperature as when lying on the surface of the ground. With glazed tile this is practically eliminated.

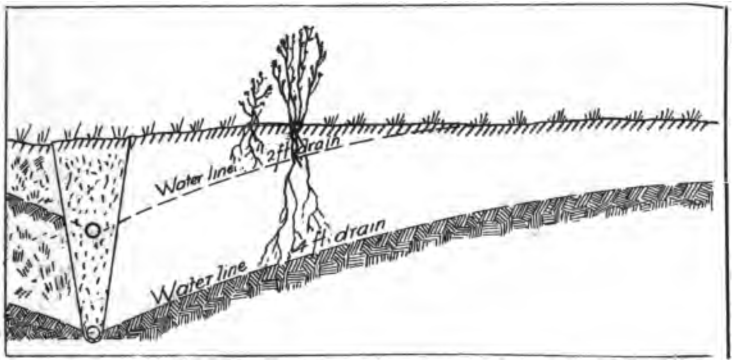

Fig. 22.—The relation of the depth of the tile to the position of the water table, and to the development of root systems in plants.

126. Replacing Broken Tile.—An occasional tile in a line may become broken and the flow of water stopped, usually giving rise to a springy condition at or near the surface. The line may be repaired by replacing the broken tile and cleaning out the material that may have entered.

Where tile are laid in clay, the velocity of the moving water is usually sufficient to carry in suspension to the outlet the silt that may have entered through the joints. This is not so with sand. It will enter the tile through almost any opening at which water will, and the grains are so large that they can not be carried in suspension. They collect in the tile and gradually fill it up. Methods of preventing this will be discussed later.

127. Cost of Tiling.—An idea of cost of tiling may be obtained from the following factory quotations:

3 inch	$11.00 per M.	Weight, 5 pounds.
4 inch	16.00 per M.	Weight, 7 pounds.
5 inch	22.00 per M.	Weight, 9 pounds.
6 inch	28.00 per M.	Weight, 12 pounds.
8 inch	35 00 per M.	Weight, 20 pounds.

The weight of the tile is a factor in determining the cost of transportation.

The current wages will determine largely the cost of laying the tile. This cost is made apparently less because the work may be done, usually during the late summer or fall of the year, at odd times when there is perhaps little else for the help on the farm to do. In any case, the cost of laying tile three feet deep ought not to exceed 40 cents a rod with average condition of wages and working facilities.

CHAPTER XVIII.

THE NECESSARY DATA.

128. Things That Must be Known. The question which was naturally uppermost in the mind of the practical student of land drainage, while we were considering the details of making the topographic map in Part I, was: Is such a map necessary? To him we would reply with another question: Is it not more economical to take a half dozen readings, each of which will tend to check the accuracy of the others, than to skip a single reading, whose omission is apt to lead to a costly mistake? Having taken these readings, he would be foolish, indeed, who did not record them in an intelligible form for future reference, and in so doing, he would, unconsciously perhaps, be making nothing more or less than a topograhpic map, — one which, to answer its purpose, should contain all of the information, a knowledge of which had better be gained before, rather than after, an attempt has been made to install a costly system of drainage. The truth of this is evident. The method of obtaining this information, however, should be made to vary with the apparent difficulties of the proposed project, and should be made as inexpensive as possible, without sacrificing efficiency.

129. A Word about Methods.—Perhaps two-thirds of the tile in operation at present in Wisconsin was laid with the aid of nothing more than a carpenter's level to obtain the total fall in a given distance; a study of the flow of surface water to ascertain how that fall was distributed; and the presence of water in the bottom of the trench to guide in making the latter smooth and sloping. If the farmer thought that there was enough available fall to give each 100 feet two inches, he built in the trench at a point where it had been finished a little dam of that height, and then finished the trench for the next 100 feet, in such a way that the water gradually decreased in thickness to zero, at the end of that distance. In the majority of cases these tile continue to return profit to their owners. But we must also remember that there are cases where the fall determined by the carpenter's level has proven inaccurate; where more digging was done than would have been necessary to accomplish the same results, if more care had been taken in laying out the system; and where by laying the tile at a slope of 2 inches in 100 feet, by the method just outlined, they had to be laid shallower than expected, or else abandoned, near the head of the line. The disadvantage of it all is that the mistakes are usually not seen, until a remedy would be costly. Suffice it, then, to say that to be consistent with the idea of economy and profit that should be the fundamental consideration in improving natural drainage, no man can afford to begin the installation of a system of tile-drainage until he has studied to the fullest extent of his facilities, the nature of the problem he has at hand. Let it be with a carpenter's level, a small drainage level, or with a fifty-dollar instrument that he and three or four of his neighbors have jointly purchased.

130. The Preliminary Survey.—The details of the topographic map were given in Chapter VIII. In the following chapter, the final levels that should be run over each line of tile, will be discussed. It is advisable, however, in any proposition, to obtain a rough idea of the topography before either of these other steps is taken. This is called a *preliminary survey,* and it consists essentially of a line of levels run from the head to the outlet of the area to be drained. This preliminary survey may give the project an entirely new aspect. The proposed work may be found to be much more feasible than contemplated, or, features may be revealed which will show additional difficulties. At any rate, the results of the preliminary survey should serve as a guide in the steps that are to follow. It is often well, while conducting this survey, to leave *temporary bench-marks*, which may be used to check the subsequent operations.

131. Study of the Sub-Soil.—An examination of the sub-soil is also a part of the preliminary survey. If there is any quick-sand to be contended with, it is better to know it before, than after, the digging is begun. Likewise, all of the properties of tile drainage which have been shown to depend upon the sub-soil can be made the most of only when a knowledge of its character is at hand.

The soil auger is the most efficient tool for this purpose. The examination should extend as deep as the tile are to be laid. The notes recorded should contain both the location of the boring and the nature of the soil found at the various depths. The position of these points on the map may be approximated by comparison with points already located by the alidade. Borings should be taken until the soil strata can be plotted in profile with reasonable accuracy as shown in Fig. 24.

On marshy areas distances to the underlying sand or clay may be found by simply pressing a pole down with the hands. The pole goes down through the muck or peat with ease, but can be made to enter the clay or sand only with difficulty.

CHAPTER XIX.

INTERPRETATION OF DATA.

132. The Extent of Data at Hand.—With sufficient study of the sub-soil, and with the topography so taken that all slopes may be safely assumed to be uniform between the points observed, there should be data enough at hand from which a drainage system may be intelligently planned by a simple application of some of the foregoing principles of drainage. Imagine if you can the map shown in Fig. 23 without the lines of tile plotted in outline or look at the map in Fig. 16, and you have the form in which a map should appear after all field observations have been made. The marsh-corners and the points at which the contour lines change in direction have been located with the plane-table and alidade. The extent of the area underlaid with sand within three feet of the surface has been found and located by reference to these points. Let us now fit a system of tile drainage to these conditions.

133. The Location of the Main.—It is reasonable to assume at the start that the main tile should follow the water-way as indicated by the contour lines, unless some very good reason is found for placing it elsewhere. The sharpness of the angle made by the 52nd contour line shows that there is a well defined, necklike natural outlet for the marsh. There is apt to be considerable surface water escaping here at times, and if the tile are laid directly beneath the center of the channel they may be unearthed by the surface water. It is better to curve the line somewhat, as indicated.

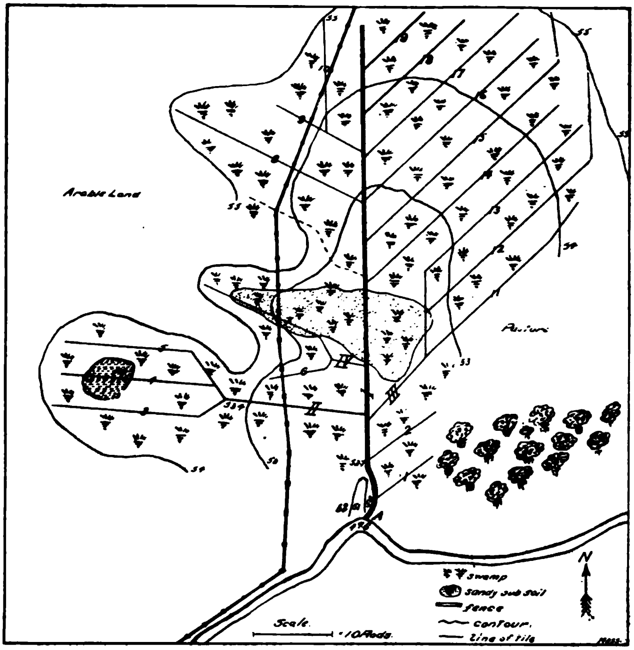

Fig. 28.—A system of tile drainage.

Farther up the marsh the water-way is not so well defined and this difficulty does not need to be met. Is there then any reason why the main should not run as indicated on the map? One alternative would be to run it in the direction of the head of Lateral 16. But the water from Laterals 8, 9 and 10, to reach this main would have to run considerably out of its most direct line to the outlet. Another scheme would be to have a sub-main where Main I now is to receive the discharge from the laterals on the left and to have another on in the place of Lateral 11. The main body of the marsh could then be drained by laterals parallel to the first sub-main and discharging into the second. The drawback with this arrangement would be that the laterals would be almost parallel to the contour lines instead of normal to them—in the direction of greatest slope. None of these locations for a main are any better or even as good as the one first selected and we will settle upon that as the general direction of the main. It is true that there would be economy in having the direction of the laterals at right angles to that of the main, thereby forming fewer acute angles and hence fewer places where the land is drained by two intersecting lines of tile instead of by the one line of tile needed. Nevertheless this short-coming is more than counterbalanced by the advantage mentioned above.

134. Nomenclature.—A few definitions are not out of place in this connection.

The *grade line* is the line lying in the bottom of the trench upon which the tile are to be laid.

The *grade* of a station is the elevation of the grade line at that point.

The *gradient* or *slope* is the ratio between the fall and the distance through which it is distributed.

The *cut* is the distance between the top of the ground and the grade line.

A *step* is the vertical drop usually allowed where a lateral joins a main. This should if possible be equal to the difference between the diameter of the main and that of the lateral.

135. Computation of Grade.—The next step is to determine the *available fall*. This can be facilitated by plotting in profile the surface of the ground along the line of the proposed main. The object of finding such intermediate elevations as the 52.7, is made evident by the profile in Fig. 24. Were it not for this elevation the profile would of necessity be taken as a straight line between the points on each side of it, as shown by the dotted line connecting those points. The sub-soil should also be plotted as shown in Fig. 24.

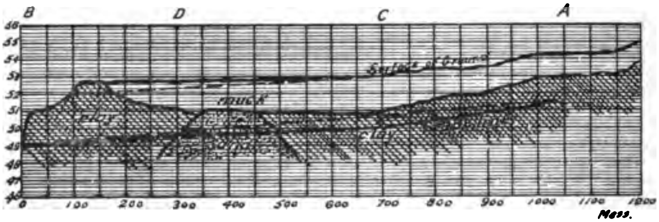

Fig. 24.—Profile of the main in the drainage system shown in outline in Fig. 23.

The simplest grade line is one extending straight from the desired depth at the head to the desired elevation at the outlet. The difference in elevation between these points is the available fall and is shown by the straight dotted line from A to B. Three feet is taken as the depth at the head and 49.0 is the trial elevation of the outlet. But we notice that at a point about 30 rods below the head, the depth is only about two feet, which is less than the initial depth. This is undesirable because the shallow portion of the line will freeze while that above, lying deeper, will continue to carry water which will freeze when it reaches the shallow spot and endanger the tile. They should be at least as deep all along the line as they are at the head, namely, three feet, and this establishes the point C. This will then necessitate a smaller gradient below C than above it, something which is undesirable because the sediment carried by the swiftly moving water in the upper end of the line will be partially dropped when the velocity of the water is checked by a diminution of the gradient. It is a case of choosing between two evils and we choose the one we think to be the lesser.

But another difficulty has arisen. The grade line running straight between C and the outlet will be deeper than the one first tried. This means that more of the quicksand will have to be contended with. We might raise the proposed outlet, but this would lessen the already diminished fall in the lower end of the line. A more advisable change would be to cut down the gradient to a minimum, e. g. to 0.1 in 100 feet until the end of the sand is reached at D about 400 feet below C. A uniform grade line from here to the outlet will be a little higher than one running in a straight line from C, and to that extent, it will be the better. The danger of the collection of sand in the tile will be eliminated by packing muck carefully around the tile before any sand is put back into the ditch.

136. Testing the Grade Line.—With the grade thus established by a "cut and fit" method it is well to see that the drainage of all portions of the marsh into the main is feasible. It is hardly necessary to plot a profile to do this. The test should be applied to the portions of the marsh apparently presenting the greatest difficulties. Take the first pocket on the left for a trial. The grade of the main at the outlet of Sub-main II will be about 49.4, and allowing 0.4 for the step mentioned in **134**, 49.8 will be the grade of the lateral. The lowest point in the pocket is 52.9, and its distance from the main is about 600 feet. It must have a fall of at least 0.6 feet in that distance. That would make the minimum elevation 49.8 plus 0.6 or 50.4, which subtracted from 52.9 leaves a depth, or cut, of 2.5. This is rather shallow, to be sure, but not seriously so. A slight deviation from established rules is more permissible in the laterals than in the main.

Apply the test to Lateral 16. The main at the outlet of this lateral is about 40 rods or 600 feet from the outlet. The profile shows that the elevation at this point is about 52.8, and that the depth is about 3.0. A glance at the contour lines tells us that the surface rises a foot in about 300 feet, and the lateral, which can be given that slope also, without sacrificing any depth, will have an abundance of fall. Likewise the surface along Lateral 8 rises two feet in about 500 feet, so we can rest assured that the grade line adopted has stood the test. Even though the surface were level in either of these places, by laying the tile shallower at the head—as shallow as 2.5 feet if necessary—they could be made to discharge into the main just the same.

137. The Grade at Each Station.—The grade of the main at each hundred-foot station may be computed here as well as later. The peculiarities of the topography and the sub-soil made it easier to begin at the head in planning the grade. The grade at A is 51.5; at C it is 50.0; at D which may be taken as just 400 feet below C, the grade must then be 49.6, or 0.4 lower than that at C; and at B the grade is 49.0 These four points establish the grade for the three sections of the main limited by each. For simplicity, the change of grade is usually made at an even station. So let us put D 300 feet from the outlet; DC has been already taken as 400 feet; and CA is then left about 350 feet long. The 0.6 feet fall in BD must then be distributed over 300 feet, and each hundred feet will have 0.2. Section DC will have 0.1 to the hundred. CA will have practically 0.4—a little more than that, to be more accurate, but where the fall is so great it is useless to compute the grade to thousandths or even to hundreths. The resulting discrepancy may be allowed for on the last station.

The grade at the various stations will then be as follows:

Station.	*Grade.*
0	49.0
1	49.2
2	49.4
3	49.6
4	49.7
5	49.8
6	49.9
7	50.0
8	50.4
9	50.8
10	51.2

138. How Stations are Designated.—The first station is numbered 0 so that the number of each succeeding station along the line will represent the number of hundred feet it is distant from the outlet. Intermediate points, odd stations, as they are called, are described with reference to their distance from the last even station below. The last station on the main is 10+50 but its grade does not need to be computed for reasons explained in 148.

139. Frequency of Laterals.—An examination of the sub-soil has shown that the most of the tile will be laid in clay. This means that with the depth chosen they will have to be four rods apart. If the average depth had been four feet instead of three they might be put six or eight rods apart. The laterals on the left of the main having the natural system of are at irregular intervals. If more short lines are needed they may be put in later as the necessity for them is seen. Probably the first line to be provided for will be one along the dotted line beginning parallel to Lateral 8.

140. Size of Tile in Laterals.—We now have at hand as much data as we can expect to have bearing upon the size of tile required. In the case of the laterals, the problem is a simple one. All of the laterals in the gridiron system should be of three inch tile. Those on the left should be of four inch tile since the proportion of seepage from the upland for each lateral to remove will be greater. This is particularly true of Lateral 7 which, being laid in sand, will have a comparatively larger area to drain.

141. Size of the Main.—There is one factor not shown by the map that must be considered in determining the size of the mains, namely the amount of land shedding its water upon the marsh. As a matter of fact, this added to area of the marsh is about 80 acres, and the best we can do is to assume that ¼ of an inch in 24 hours will have to be removed from this area. With the use of the table in **108** it will be seen that 10 inch tile is the smallest that can be used. If the slope of the sides of the catchment basin were greater than three or four feet to the hundred, a correction would have to be made for the area. With a slope of ten feet to the hundred, the area of the land so sloping to the marsh would have to be doubled in gathering data from which to estimate the size of the main required. Where there is an open ditch in good condition remove a portion of the water, an allowance may be made in the other direction.

The main and sub-mains will then have the following sizes:

Main I	
To Sub-main II	10 inches
To Station 7	8 inches
Remainder	6 inches
Sub-Main II	5 inches
Sub-Main III	5 inches
Sub-Main IV	4 inches
Sub-Main V	4 inches

142. Other Considerations.—Main I is not reduced in size below 8 inches until Sta. 7 is reached because of the limited fall in the main up to that point. Sub-mains IV and V are made no larger than four inches because, although each receives the discharge from two laterals, neither has any more water to remove than Lateral 8, which is only four inch tile.

Main I might also be reduced to four inches at its head but for another condition not shown on the map. There are about four acres of marsh north of the area mapped, and belonging to a neighbor who has promised to pay twenty-five dollars toward the construction of the proposed main. He therefore has a voice in the matter. A reading taken when the levels were run showed that this land had sufficient slope for drainage into the main as planned. This is but one example of the many ways in which neighbors may coöperate with mutual advantage in land drainage.

The general plan of the system is now complete. The laterals should not be taken as finally located until they are staked out in the field. The method of procedure is taken up in the next chapter.

CHAPTER XX.

LAYING OUT THE DRAINS IN THE FIELD.

143. The Irregular Laterals.—The laterals that are to have the natural system of grouping on the area at the left of the main may be most advantageously staked out as they are being planned. They will be irregular at best and should be placed where a more local study of the topography, and the general data recorded on the map seem to dictate. They need not be straight. Let them curve for any good reason, as for avoiding a depth that would be too expensive. Join lines like Laterals 3, 4 and 5 by a sub-main before the point marked 53.4 is reached. A line should be made to run like Lateral 4 through the wettest part of each pot hole, and should extend until the dry land beyond is reached. Laterals 6 and 7 are given the direction indicated on the map because they will drain a wider area and do it just as well as if thy ran in a straight line from their respective heads to the head of Sub-Main IV.

After the direction of these irregular laterals has been definitely decided upon, and a flag has been put at each point of curvature, beginning at the outlet, the length of each should be measured with a chain or tape. A long stake or flag put every hundred feet along the line will serve as a "finder" for a hub driven flush with the ground exactly at the hundred foot mark, to be used for reference later. These points are known as *stations.* By having the stations thus equi-distant from each other, the computation of grades is facilitated, as was noted in **137.** Points of intersection of curves are odd stations and as such are described (**138**).

144. The Parallel Laterals.—Since uniformity is desired as far as convenient, more care must be taken in laying out the laterals in the gridiron system. The general direction of the laterals has been decided upon. It is now necessary to establish a definite direction, and we settle upon that of Lateral 11, which is staked out accordingly. It is the perpendicular distance between the laterals which is to be four rods, so perpendiculars must be erected to the lateral, the first one near the outlet. This may be done approximately by the eye, or more accurately by setting off a right angle with an instrument or with a tape according to the *three, four and five* method (**21**). Flags put at intervals of four rods on this, and the perpendicular erected near the head of the base-lateral give direction and location to the parallel lines. Another flag put on the main line with the two already set for each lateral, mark the outlet of each. Each lateral may then be measured and staked every hundred feet from its respective starting point. Laterals 12 and 13 are given a sub-main to avoid any more digging in the quicksand than is necessary to place the tile where it will remove the water from the sand. The outlets of the laterals will be odd stations on the mains, and should be recorded in consecutive order with the even stations in the field book. A care well worth the taking is to curve the end of every third lateral as Laterals 12 and 15 are curved to intercept the seepage from the adjacent hill. With all lines of tile measured and the stations marked with hubs and flags, the land owner knows just how many tile of each size he will need. About 4% should be allowed for breakage.

145. The Final Levels.—The next step is to find the elevation of each station on each main and lateral in the system. Then for the first time we are in position to plot the laterals in profile. The grade for each lateral is to be computed independently of all others after the method employed in **135.** Slight changes in the position of individual laterals may be made even at this late stage, but none that will affect the system os a whole, and each change should be indicated on the map.

For convenience in further work the elevation of all stations are here given in tabular form. The length of all mains and laterals is given in parenthesis after the name of the line. Odd stations described as 0+40 (1) means that Station 0 of Lateral 1 is at 0+40 on Main I. Odd stations followed by (c) are at points of intersection of curves. The elevation of Station 0 on all laterals is given as that of an odd station on the main or sub-main.

TABLE X.

The actual elevation of all stations provided for in the map.

Station.	Elevation.
Main I (1050).	
0	52.14
0+40 (1)	52.26
1	52.40
1+30 (2)	52.66
2	52.64
2+5 (III)	52.70
2+10 (II)	52.73
3	52.60
3+10 (IV)	52.55
4	52.64
4+90 (14)	52.60
5	52.67
5+72 (15)	52.90
6	53.02
6+30 (8)	53.06
6+54 (16)	53.12
7	53.24
7+36 (17)	53.50
7+38 (V)	53.54
8	53.64
8+18 (18)	53.80
9	53.96
9+2 (19)	54 10
10	54.54
Main II (330)	
1	52.80
2	52.91
2+90 (3)	52.95
3	52.87
3+30 (4)	52.76
Main III (232).	
1	52.80
1+50 (11)	52.84
2	52.67
2+32 (12&13)	52.70
Main 1V (70)	
0+70 (6&7)	52 70
Main V (90).	
0+90 (9&10)	53 96
Lateral 1 (150).	
1	52.76
Lateral 2 (180).	
1	52.74
Lateral 3 (360).	
0+70 (c)	53.54
1	53.60
2	53.08
3	53.76
Lateral 4 (320),	
1	53.24
2	52.91
3	52.87
Lateral 5 (340).	
0+80 (c)	53.06
1	53.10
2	52.86
3	53.42
Lateral 6 (140).	
0+20 (c)	52.74
1	52.96
Lateral 7 (320).	
0+50 (c)	52.80
1	52.94
2	53.00
3	53.81
Lateral 8 (430).	
1	52.98
2	54.03
3	54.27
4	54.66
Lateral 9 (200).	
1	54.37
2	55.00
Lateral 10 (230).	
1	54.36
2	54.90
Lateral 11 (440).	
1	53.20
2	53.56
3	53.90
3+40 (c)	54.16
4	54.24
Lateral 12 (640).	
1	53.17
2	53.42
3	53.77
4	53.90
4+40 (c).	54.38
5	54.70
6	54.89
Lateral 13 (400).	
0+80 (c)	52.77
1	53.24
2	53.98
3	54 20
4	54.67
Lateral 14 (530).	
1	53.80
2	53.97
3	54.00
4	54.20
5	54.42
Lateral 15 (650).	
1	52.90
2	53.24
3	53.70
4	54.14
5	54.55
5+30 (c)	54.84
6	55.06
Lateral 16 (480).	
1	53.24
2	53 54
3	54.08
4	54.86
Lateral 17 (420).	
1	53.56
2	54.01
3	54.62
4	54.80
Lateral 18 (275).	
1	54.21
2	54.47
Lateral 19 (170).	
1	54.38

146. When to Run the Final Levels.—It would perhaps not be advisable to take all of these elevations on the same day unless there is reasonable certainty of laying the tile within a week or two, because some of the hubs may be disturbed and the elevation previously found will be incorrect. In taking elevations as well as in setting grade stakes, an operation about to be described, it is usually a waste of time to work more than three laterals ahead of the crew laying the tile. The least possible chance for error is, of course, when elevations are taken and grade stakes are set on a lateral just before the digging crew start working upon it.

147. The Grade Lath.—With the grade line established, the next step is to dig the ditch true to it. No man can place his eye on the grade line and sight along the bottom of the ditch to the station below. If the sighting method is to be used, it must be done above ground. Let the line taken be parallel to the grade line and five feet above it. A ditch dug true to this line will be true to the grade line. Where the cut is more than five feet the line of sight may be taken six or seven feet above the grade line.

But first we must set the grade stakes or laths that will define such a line. A lath about three feet long and supported at each end is better than a stake for two reasons. First, a stake would have to be removed upon digging the ditch, and second, it is difficult to sight over a narrow stake. Then also, fewer laths are required in sighting around a curve.

148. How to Set the Grade Lath.—At each station we have a point from which to work, namely, the top of the hub flush with the ground, whose elevation is known. We know that the elevation of Station 0, Main I, is 52.14. Its grade is 49.0 and the cut is then 3.14—that is, the top of the ground is 3.14 feet above the grade line. But we want our grade lath 5.0 feet above the grade line, or 5.0 feet minus 3.14 feet, above the ground. A lath then, nailed upon two stakes previously driven one on each side of the proposed trench, with its top 1.86 feet above the hub will be in place. Following the rule that 5.0 minus the cut is the distance at which the grade lath should be above the hub, the interval is found to be 2.0 feet at Station 3. The laths at Station 1 and 2 may now be put in on line with those at Stations 0 and 3. The laths should be set with reference to the elevation of the station at all points where the grade changes—the points which establish the grade, and at as many intermediate points as are necessary to insure the setting of the remainder of the laths with accuracy by sighting. The lath at the odd station at the end of a line of tile may be set by sighting up from below over the laths already set.

149. The Grade Notes.—Grade notes for setting grade-stakes on Sub-Main II and Lateral 3 would appear in the field book as follows:

TABLE XI.

A form in which grade notes may be kept.

Station.	Elevation.	Grade.	Cut.	Interval.	Remarks.
		Sub-Main II.			Barker and Davis. Sept. 17, 1907.
.0	52.73	49.7	3.03	1.97	
1	52.80	49.8	3.00	2.00	
2	52.91	49.9	3.01	1.99	
2+90	52.95	49.99	2.96	2.04	Outlet of Lat. 3.
3	52.87	50.0	2.87	2.13	
3+30	52.76	50.03	2.73	2 27	Outlet of Lat. 4.
		Lateral No 3.			
0	52.95	50.1	2.85	2.15	
0+70	53.54	50.17	3 37	1.63	Point of intersection.
1	53.60	50.2	3.40	1.60	
2	53.08	50.3	2.78	2.22	
3	53.76	50.4	3.36	1.64	

The fall in 90 feet will be .09 and from this the grade 49.99 at Station 2+90 is obtained. The grade for Station 0+70 Lateral 3 was similarly found.

150. The Check-Levels.—After the grade laths are set it is well to check the accuracy of the work, with a level. The level is set up and a back sight taken so that the H. I. will be known. Then knowing the elevation that the grade lath should have the difference between this and the H. I. may be found. The target set at a rod-reading, R. R., equalling this difference, should when held upon the lath, be hit by a line from the cross hair of the instrument. If it does not, there is an error somewhere which should be located and corrected before any serious results occur. An error not greater than .01 feet may be disregarded.

For running these check levels the following form of notes may be found a convenient one:

TABLE XII.

A form in which the notes for check-leveling may be kept.

Station.	Grade.	Lath.	H. I.	R. R.	Remarks.
Lateral 3.					Levelman, Barker. Rodman, Davis.
0	50.1	55.1	57.28	2.18	(B. M.) 52.67+(B. S.) 4.61=57.28 (H. I.)
0+70	50.17	55.17	"	2.11	
1	50.2	55.2	"	2.08	
2	50.3	55.3	"	1.98	
3	50.4	55.4	"	1.88	

With the grade laths set and checked, all is in readiness for the digging of the trench.

CHAPTER XXI.

DIGGING THE TRENCH.

151. How to Use the Grade Laths.—Nothing has been said yet as to just how the grade laths are to be used. It is a simple method and more accurate than any which involves the use of a string, because a string supported by the grade laths will sag in the center—something which a line of sight will not do. The man finishing the trench is provided with a three or four inch board whose length is equal to the height of the grade lath above the grade line. At any station he digs until this standard, held vertically, reaches the top of the grade lath. At points between the stations the test is whether or not the line of sight from any two laths just hits the top of the standard when properly held. Evidently, then, for each line of tile, however short, there must be at least three grade laths—one at each end of the line and another near the center, so that at any part of the trench there will be two laths on one side or the other over which to sight.

152.—Begin to Dig at the Outlet.—The outlet of the main is the proper place at which to begin digging the trench. This provides an outlet for any surface water which may be on the marsh, and the work of digging is made cleaner and easier. On areas extremely marshy in character, it is well to allow the trench to remain open for a few days for this purpose. A trench dug about to grade at the outlet but decreasing in depth to a single spading at the head, is advisable at this stage for two reasons: The sides of a trench only partially dug are not so apt to cave, and secondly, the bottom of a trench thus dug will have a greater slope than if finished. The removal of the water is thereby hastened.

153. Grade Laths Not Needed at First.—Where the surface drainage just mentioned is first necessary, the hubs at the stations need not be put in until this is accomplished. The earth in such places is too soft to hold a hub firmly, until the water has been removed. Then also the opening of the trench past a station would result in the disturbance of the hub before the grade lath could be set with reasonable certainty of its remaining in place. The changes in position of laterals sometimes made when the final levels are run seldom need to be made on these areas because of the uniformity of topography. The soil is usually of muck or peat which will stand for some time without caving. The flag put every hundred feet when the lateral was laid out, may be put a foot or two on one side of the line as a reference point from which the hub is to be driven later at the side of the trench. All of this must of course be done before the grade lath is set.

154. Beginning the Trench With a Plow.—Where a plow is to be used to remove the first spading from the trench, the setting of the hubs and grade stakes must be postponed until the work with the plow is finished. They may then be set as above directed.

Land firm enough to admit of plowing is apt to be slightly rolling and it may be wise to take the elevation of the ground every hundred feet, to ascertain the advisability of a slight change in the position of the line before the plowing is begun. In tough sod the plow may be used advantageously, but even there, the furrow is left too near the trench, whose sides must be trimmed with a spade later. In ordinary trenches the top ten inches can be easily removed at one spading, so the advantage of using the plow is doubtful.

155. Marking with a String.—It always pays to stretch a string at each side of the trench to serve as a guide in marking the sides. These strings may be removed as soon as their position is marked on the ground by cutting the sod with a spade. This insures a straight trench and adds to both the neatness and economy of it. Around a curve a string is particularly helpful, because it is the simplest way of laying out a curve that will contain no sharp turns.

Nothing as yet has been said about the sharpness of curves permissible. There are cases which seem to require curves thirty feet long or more, but none of those shown in Fig. 23, except the one at the outlet of the main. Where a lateral joins a main, the trench should be made to curve from a point about four feet back of the lateral, to one on the main about a foot below where the lateral would have intersected had it been made to run straight. This gives the discharge of the lateral a slight initial velocity toward the outlet of the main, which is all that is desired.

156. The Tools Used.—For removing the top spading, nothing is better than a square bladed spade. As the more resistent clay of the sub-soil is reached, a long-handled pointed shovel can be made to penetrate it more easily. It is economical to remove the last foot of the trench with a narrow tile spade, where tile of a small size is to be laid. The trench cleaner is used to finish the trench, leaving it with the same degree of curvature as the exterior surface of the tile.

157. Width of the Trench.—The top width of the trench should be such that a man may stand in the ditch and work with comparative ease. A width of 14 inches tapering to that of the outside of the tile at the bottom is usually sufficient for a ditch three feet deep. A four foot ditch requires about a 20-inch top. In a loamy or sandy soil the top of the trench should have greater width to prevent caving. Some brittle clays like the red clay of the Lake Superior region are apt to do this also when dry.

158. The Berm.—The distance that the earth excavated should be removed from the trench should vary with the danger of caving. However, in any case it is well to have it removed far enough that lumps will not be continually rolling back into the ditch to impede the laying of the tile. Where all of the dirt is thrown on one side of the ditch the other is left clean for convenience, but in the case of a sandy sub-stratum some of the top soil should be thrown on this "clean" side, where it will be easily available for packing around the tile before the sand is thrown back.

CHAPTER XXII.

LAYING AND COVERING THE TILE.

159. When Tile May be Laid from the Head.—A brief mention has been made of the fact that some areas require that the trenches, partially finished, be left for some time to remove the surface water. If this could be carried a step farther—far enough to allow the trench to be dug to grade for the entire length of the line without a probability of caving, we might begin to lay the tile at the head and work down stream to the outlet. This is the safest way to lay tile because the water continually flowing washes out of the tile all obstacles to flow, such as clods of earth which may in some way have entered. Then too the man laying the tile can see by the way in which the water stands or runs down the trench below, whether or not it has been properly finished. But in many soils this works better in story than in fact. If the trench is five hundred feet or more in length, the lower end of it must stand finished and open for at least a day, and that is longer than many soils will stand in the presence of running water. The tendency to cave will increase with the amount of sand and water present. This being the case, we are most always compelled to begin at the outlet and lay the tile "against the tide." All clods of earth carried along by the water will enter the tile unless care is taken for its prevention—a care which must be taken. The trench need not be finished for more than a few feet ahead of the tile—in quicksand not more than two feet, and muck should be packed around the tile as soon as they are laid.

160. How to Join a Lateral to a Main.—Still another small advantage results from working up stream from the outlet. The laterals may be joined to the main more easily. When a lateral has been laid to meet the main, the last tile used will have to be cut to an odd length in order to connect the tile above with the main. It is not necessary to take such care with the length of the last tile on the upper end when the line is laid from the outlet.

Laterals may be joined to a main either by Y's made at the factory or by chiseling a hole in the side of the main, a little above the center and large enough to allow the lateral to enter.

161. Hauling the Tile to Place.—But before the tile can be laid they must be hauled upon the ground. On soft, boggy areas, this is quite a problem. About all that can be done is to haul them with a team and wagon as far as the horses can walk without becoming mired. The tile must be carried the rest of the way by hand. A convenient scheme is to string them on gas pipes ten or twelve feet long. Two men can carry two of these with comparative ease.

The tile should be placed on the clean side of the trench, strung out end to end. It is a mistake to throw them down carelessly where mud will adhere to the sides, later perhaps by simply lying over night in the late fall, to freeze and be in the way when an attempt is made to lay the tile on the bottom of a smooth trench. It is better to pile the tile in piles of about five each as they are needed along the line. These piles, or any others, should not be placed where surface water is apt to stand. Farmers frequently make the mistake of taking advantage of the frozen condition of the marsh in the winter by hauling the tile into place then, only to find then frozen full of ice which is sure to form during the sudden changes of temperature that usually accompany the melting of the snow. Over half of the tile may be ruined in this way.

Pile the tile on a convenient dry spot, preferably near the outlet, when they are hauled from the car. If the laterals are filled so that they are made passable as soon as they are completed, the tile for the next lateral may be hauled into place over the ground made firm by the drainage afforded by those laid.

162. Protection of the Outlet.—Tile-laying, then, usually begins at the outlet of the main. This needs protection from exposure to the weather. A two foot length of glazed sewer-pipe large enough that the tile fits into the bell is commonly used. A plank box about four feet long will do equally well. Where either is used, however, the end exposed should be low enough to allow for heaving. The exposed end of the outlet should be screened for a protection against the entrance of musk-rats, rabbits and other small animals.

163. Tools Used.—Tile larger than four inches can be laid most easily by hand. Three and four inch tile may be handled very well with the tile hook shown in Bul. 138. In addition to this, the man laying the tile needs a grade-standard, so that when the water in the trench seems to indicate that the bottom has not been properly finished, he can test it by sighting.

164. Permissible Openings—Patching.—It is not safe to allow openings at the joints to be greater than ⅛ of an inch wide. Bul. 138 shows how tiles with irregular faces may be rotated until the joint is sufficiently tight, and there is no kink in the line. Sometimes it is impossible to do this, but in such cases broken tile may be used for patches. The same may be done where just a small notch is broken out of an otherwise solid tile. These patches fit better when pieces are used of tile larger than that to be patched. Pieces of four-inch tile fit nicely over the three-inch.

Broken tile occasion less risk when they are placed at the head of the line, where, if they do fill up, they will not cripple the remainder of it. The use of a tile well patched is more warranted than that of a tile only cracked, but with no piece broken out. The presence of a flaw in a tile is easily detected by the sound when handled. Any pieces of broken tile not otherwise used, placed around the open end at the head of a lateral will serve as a filter.

165. Blinding the Tile.—Fine earth packed at the sides and on the top of the tile to a depth of four inches will keep them in place. Where the trench is made no wider than the tile, less attention need be given to packing. Tile laid in sand, however, require a trench wide enough to leave a two inch space on each side of the tile. This gives an opportunity to pack peat or muck all around the tile. With this done only on the top as when the trench is narrow, the interior of the tile will tend to fill up with sand to a height equal to that at which the protection of the muck begins on the outside.

166. Filling the Trench.—After the tile has been properly blinded, the remainder of the ditch may be filled with a team on one side hitched by a long chain to a scraper on the other. As soon as the scraper is dumped the team backs up for another load. In soft, rough ground it is difficult for the team to back up, so a heavy plank drawn at an angle up the ditch is perhaps the next best thing. A plow with a long evener is sometimes used, as soon as the tile are blinded. When enough earth has been rolled back into the ditch by any of the methods, a plow with an ordinary evener may be used. Care must be taken if the earth is wet, not to allow a horse to walk in the trench as long as there is any danger of stepping through to the tile.

167. Filling by Cultivation.—It is advisable to raise a cultivated crop on the land for at least two years after it is drained, before it is seeded to grass. The earth put back into the trenches will continue to settle for some time and cultivation will tend to fill the depressions there formed.

If these depressions are left unfilled, the surface drainage will be somewhat improved, but the effect upon the discharge of the tile will not be marked. The unpacked condition that will prevail for a few years in the earth that has been thrown back into the trench, does not facilitate the movement of the water toward the tile as much as might be supposed. The experience of farmers bears out the contention that the tile will be more efficient during the second and subsequent years, than during the first.

168. Conclusion.—The difficulties met with in designing a system of drainage adapted to the area shown in Fig. 23, were comparatively few. Another area might not be favored with so much fall; it might be subject to more water from above and back-water from below or it might be so large as to require an open ditch to assist the tile. Silt wells, catch-basins, submerged outlets, and the other devices mentioned in the bulletins used for reference, have not been considered. This must not be taken to mean that they would not be necessary under the more unfavorable conditions. To recognize these conditions, and to meet them according to their merits, are the first duties of the drainage engineer.

QUESTIONS ON PART TWO.

CHAPTER IX.

1. What is "the duty of water"?
2. Discuss the relation between irrigation and drainage.
3. Discuss the fluctuations in rainfall.
4. Name and give the limits of the three periods into which the rainfall year is divided.

CHAPTER X.

5. Name the four ways in which rain-water is disposed of.
6. Discuss the difference between percolation and seepage.
7. Discuss the relation between the run-off and the percolation.
8. Name factors that influence each.
9. How does the standpoint of the drainage engineer differ from that of the hydraulic engineer?

CHAPTER XI.

10. Name and describe the three forms of soil moisture.
11. Define (1) water-holding capacity of soil; (2) an open soil; (3) a retentive soil.
12. What is meant by mechanical analysis of soils?
13. Discuss the relation between the mechanical composition of a soil and the rate at which water will move through it.
14. Describe (1) the flocculated condition, and (2) the puddled condition, of clay.
15. Discuss other factors influencing the rate of movement of underground water.
16. Name and describe the three zones of flow.
17. Describe a hardpan. Discuss its effects.

CHAPTER XII.

18. Describe briefly, the rock layers.
19. Tell of changes that have taken place in the natural surface drainage of Wisconsin.
20. Discuss the changes that are taking place at present.

CHAPTER XIII.

21. Describe the three classes of land that require artificial drainage.
22. To what extent is drainage warranted?
23. Cite some specific cases of benefits derived from artificial drainage, and given in Bulletin 138.
24. Discuss how standards change, as regards the extent to which artificial drainage is profitable.

CHAPTER XIV.

25. By what two general methods is artificial drainage effected?
26. Discuss the underlying principle.
27. Discuss the slope that the sides of open ditches should have.
28. Define (1) waste bank; (2) berm.
29. Describe the dredges commonly used at present.
30. Discuss disadvantages of open ditches.
31. Explain how lines of tile and open ditches work hand in hand.
32. Discuss the use of dead-furrows and dykes for drainage purposes.
33. Name the devices that were used for under-drainage before cylindrical tile came into use.

CHAPTER XV.

34. Define (1) wetted perimeter; (2) hydraulic mean depth.
35. Name the two factors that determine the discharge.
36. Describe the sub-surface float.
37. Describe the current meter and tell how to use it.
38. Name some of the requirements of a weir.
39. Give the formula for the flow of water in open ditches.
40. Define (1) actual capacity; (2) required capacity.
41. Compare the various units of water-measurement.

CHAPTER XVI.

42. Discuss the two factors upon which a drainage tax should be based.
43. Describe the method of adjusting the drainage tax and preparing the assessment roll.
44. Describe the effect of efficient drainage upon the flood flow at the outlet.
45. Discuss the tax upon odd corners and "islands."

CHAPTER XVII.

46. Describe three general classes of tile-drainage systems.
47. Define (1) head; (2) outlet; (3) lateral; (4) main; (5) sub-main.
48. Discuss the advantages and disadvantages of double-main systems.
49. Discuss the comparative merits of glazed and unglazed tile.
50. Name and discuss a factor upon which the size of a main should depend, but of which that of the lateral is independent.
51. Discuss the relation between (1) the depth and frequency of tile; (2) the frequency and the size; (3) the frequency and the kind of soil; (4) the slope and the size; (5) the depth and the rapidity of drainage; (6) the depth and the duration.
52. Discuss the effect of frost upon tile.
53. How may broken tile be detected? Replaced?
54. Compare sand, silt, and clay, as to their tendency to settle in the tile.
55. How can the farmer cut down the apparent cost of the labor which tile-laying involves?

CHAPTER XVIII.

56. Discuss the necessity of the topographic map.
57. How can the flow of water be made to assist in securing accuracy in the preparation of the trench for the tile.
58. What three steps are there, which, consciously or unconsciously, are followed in the surveys for tile drainage?
59. Describe the methods and importance of making and recording borings.

CHAPTER XIX.

60. To what extent should the elevations have been taken in preparing the map?
61. Discuss the factors to be considered in locating a main.
62. Define (1) grade-line; (2) grade; (3) gradient; (4) cut; (5) step.
63. Name the two points that establish the grade.
64. Name some of the factors to be considered in distributing the fall.
65. What is meant by "testing" the grade of the main?
66. How is the grade computed for each station?
67. How may neighbors coöperate in tile drainage?

CHAPTER XX.

68. Describe how irregular laterals may be laid out.
69. How may the laterals be made parallel?
70. Discuss the necessity and method of running the final levels.
71. Describe the grade-lath.
72. Tell how it is set.
73. Describe the method of running check levels.

CHAPTER XXI.

74. Tell how the grade-lath is used.
75. Why should digging begin at the outlet?
76. Discuss the use of the plow for starting the trench.
77. Describe the method of marking out the trench.
78. What factors should determine the width of the trench?
79. Why should one side of the trench be kept clean? When is there an excuse for not doing so?

CHAPTER XXII.

80. When may tile be laid from the head? State the advantage.
81. Describe the method of joining a lateral to a main.
82. Discuss the methods of hauling tile into place.
83. How should the outlet be protected?
84. Tell how patching may be done. Make suggestions.
85. Discuss the limit of permissible openings in the joints of the tile.
86. Name precautions to be taken in blinding the tile.
87. Name and discuss the various methods of filling the trench.

PROBLEMS IN PART II.

1. Reckoning the weight of water as 62.5 pounds per cubic foot, compute the average weight of water per acre that fell as rain on Wisconsin land in 1906. In 1907.
2. A ditch dug entirely in peat at 8 cents a cubic yard, is 6 feet wide at the bottom, 8 feet deep (6x8), and has side slopes of 1:1. What will the excavation cost per rod?
3. Compute the cost per 100 feet, of the ditch described in Problem 2, if the sand came within 5 feet of the top, and was handled for 12 cents a cubic yard, the cost of handling the peat remaining the same as before.
4. If one end of a 100-foot section of a ditch, 6 feet wide at the bottom, with side slopes of 1½ to 1, is 8 feet deep and the other end is about 5.5 feet deep, what is the total excavation? If it were 8 feet deep at one end and 7 at the other?
5. A 100-foot section of a ditch 10 feet wide at the bottom and with side slopes of 1:1, has the following depths: Lower end of section, 6 feet; 45 feet above the lower end, 8.5 feet; and at the upper end 6.5 feet. Compute the volume of the entire section.

   Rule: Find the two end areas of the section. If the difference between two corresponding dimensions in the two areas is two feet or greater, construct a middle section. Multiply this by 4, add the two end areas, and divide the sum by 6. If the two end areas have no corresponding dimensions differing by more than 2 feet, simply take an average of the two, for the average cross-section of the ditch.
6. The depth of the water running in a ditch 24 feet wide is as follows: Sta. 0 + 2 = 2.0; sta. 0 + 6 = 3.7; sta. 0 + 10 = 4.0; sta. 0 + 14 = 4.2; sta. 0 + 18 = 2.8; and sta. 0 + 22 = 1.9. The average velocities found by a current meter at those points are: 1.19, 1.96, 2.20, 2.32, 1.82 and 1.27 feet per second, respectively. What was the total discharge of the stream? Design a ditch with a flat bottom, carrying 6 feet of water, and with a fall of 3 feet to the mile, that will have approximately the same discharge.

7. Reduce the discharge over a 2-foot weir with a 3-inch head, to miner's inches.
8. How wide will an 8-foot ditch have to be, with a fall of 5 feet to the mile, to remove the probable surface water from 16,000 acres of marsh, when flowing at a depth of 6 feet, where there are 15,000 acres of clay upland sloping at perhaps 30 feet to the mile, that shed surface water upon the marsh?
9. Design a ditch for the drainage district shown on the map, assuming that the runoff from an area of upland, averaging ½ mile in width, and sloping at about 20 feet to the mile, will have to be handled. The fall in the ditch will be 3 feet to the mile.
10. Compute the excavation necessary in the above ditch.
11. Design the main lines of tile for each of the two areas shown on the topographic maps.
12. Readjust the rating of the land in the drainage district, in accordance with the benefits that would be apparently conferred, if the plans called for but a single ditch, running north along the east line of Sections 9 and 4.
13. Compute the grade, and write grade notes for Lateral 13, in the system planned in outline, using (1) a depth of 3.0 feet at the head and (2) a depth of 3.5 feet at the head.
14. What readings would be obtained on the grade laths at each station on this lateral, upon taking the check-levels with a H. I. of 57.74?
15. Compute the cost of the tile system designed in outline, with 10-inch tile costing $50 a thousand and the rest of the tile costing at the rate given in (127), the freight and hauling by wagon costing $40 per car-load. Let 35 cents a rod be the average cost of digging, laying and blinding.

Note: 6,000 3-inch, 3,500 4-inch, or 900 10-inch tile (others ranged accordingly) make an average car-load. The tile may be nested, but no car should be loaded with more than 30,000 pounds.

Part Three.

LABORATORY AND FIELD PRACTICE.

EXERCISES IN MAPPING.

1. **With the aid of a protractor, transfer the three topographic to detail paper, changing the scale in each case.**
2. **Upon these maps design in outline a system of tile drainage, and compute the grade of the main in each case.**

PLANT HOUSE EXERCISES.

1. **For practice in the use of the level run a line of levels over the circuit outlined in the green-house. (If the weather is agreeable, a line may be run from the Soils Building B. M. to the mark on the front step of the Dairy Building, instead.)**
2. **From the same set-up of the level, determine the elevation of a number of points in the plant-house.**
3. **Taking a base-line 25 feet long make a plane-table map of the area staked out, in the plant house.**
4. **Set up the plane-table over an unknown point, and locate it by resection from three known points.**
5. **Compute the grade, set the grade-laths, dig the trench to grade and lay at least 20 feet of tile, in the portion of the plant house devoted to that purpose.**
6. **With a hammer and chisel, cut a hole in an 8-inch tile large enough to receive a 3-inch tile.**
7. **Read the soil thermometers daily that are placed in the two boxes of soil, to which the same amount of water has been added, yet one of which is provided with under-drainage and the other of which is not.**

LABORATORY EXERCISES.

1. Check the discharge over the Cippoletti weir in the laboratory with the weir formula. Use at least four different heads.
2. By means of the Bennigsen flask, perform a comparative mechanical analysis upon two soils differing in texture.
3. Cover the end of each of five glass tubes with cloth and fill one tube carefully with sand of No. 20 size; another tube with No. 40 sand; a third with No. 60; and a fourth with No. 80. Fill the fifth tube with clay loam soil that has been air dried and passed through a 20-mesh sieve. Set up the tubes in the special frame and place the cloth covered ends in water. Take measurements of the height of the water in each tube at the end of 10 minutes, at the end of 20 minutes, at the end of 30 minutes, one hour, and 24 hours.

   Plot curves on the same sheet of cross-section paper for each column of soil, using heights to which moisture rises as abscissae and the time as ordinates. Plot each curve in a different color.
4. Place 1000 gms. of fine, dry sand in a percolator, shaking it down well. Saturate with water and let it stand until it practically stops dripping.

   Determine per cent of capillary water retained, by drying to constant weight a sample of 100 gms. from the top, and 100 gms. from the bottom of the percolator.
5. Apply water under pressure to the cylinders, each of which is filled with sand of a different grade. Note the rate at which water flows through each. Use different heads of pressure.

FIELD WORK.

Note: The students will work in pairs. An effort should be made to keep the same partner throughout the course.

PROBLEM 1.

Adjust the Wye level.

PROBLEM 2.

Adjust the Dumpy Level.

PROBLEM 3.

Run levels from L., a B. M. at the edge of the lake directly north from the Horticultural Building, to Station A at the intersection of the dairy walk with the Linden Drive walk. Datum: L = 848.06. Close the line by running back to L.

PROBLEM 4.

Chain around Farm I, ABC, chaining each line twice. Station A is the apex of the "A" at the intersection of the dairy walk with the Linden Drive walk; Station B is the "X" on a boulder flush with the ground about 20 feet north of the railroad, and about 100 feet west of the street car crossing; Station C is the stake near the tree south of the new Agronomy Building.

PROBLEM 5.

Run a line of levels around Farm 1. Distribute the error of closure.

PROBLEM 6.

The class will meet some evening to stake out a meridian with the aid of the north star.

PROBLEM 7.

Check the accuracy of this meridian by making observations on the shadows cast before and after noon. Make observations at 11 o'clock and again at 1 o'clock.

PROBLEM 8.

Using the meridian for the datum azimuth, run a traverse around Farm I, by reading the horizontal circle of the level.

PROBLEM 9.

Select a 300-foot line in a convenient place and make a plane-table map of the area bounded on the south and west by the drive cornering in front of the horse-barn; on the north by the lake; and on the east by the drive along the orchard, and a straight line extending therefrom to Linden Drive. Make the map at the scale of 100 feet to the inch. Locate buildings and fences. Mark the ends of the base-line with permanent stakes.

PROBLEM 10.

Using a Wye level trace the 850th contour line on the area mapped in Problem 9. Then run levels until the level is set up with the H. I. accurately determined, but approximately 860. Revolve the level, note the path of the line of sight, and locate the 860th contour line on the map accordingly. Similarly put in contour lines at intervals of 10 feet, until the top of the hill is reached.

PROBLEM 11.

Make a plane-table map of the enclosed area lying west of the creek, and extending from the lake to the railroad. Put in the contour lines by any method that you think the most convenient.

PROBLEM 12.

Plan a system of tile drainage for the area mapped in Problem 11, stake out the main, and write grade notes for each odd and even station thereon.

PROBLEM 13.

Determine the available fall, set the grade-laths, dig the trench to grade, and lay and cover the tile permanently, for a portion of a lateral. (About eight men will constitute a party. Each party will be expected to lay 50 feet of the lateral.)

PROBLEM 14.

Run a line of levels from the lake to the center of the waterway near the crossing about a half-mile west of the railroad bridge. Make such observations as should be included in a preliminary survey. Make a rough sketch of the area covered.

PROBLEM 15.

Datum: The Hill Farm is the NW.¼ of Sec. 20, Town 7, Range 9 E. Find and sketch the NW.¼ NE¼ Sec. 16. (A different forty will be assigned to each party.)

APPENDIX.

TRIGONOMETRIC DEFINITIONS AND FORMULAE.

I. The *sine* of an angle in a right triangle, is the side opposite divided by the hypothenuse.

II. The *cosine* is the side adjacent divided by the hypothenuse.

III. The area of a triangle is

$$\sqrt{s(s-a)(s-b)(s-c)}$$

where a, b, and c are the three sides respectively, and s is one half of their sum.

IV. The value of the angle x may be found from the formula,

$$\sin\frac{x}{2}=\frac{a}{2b}$$

where b represents the sides adjacent (taken equal) and a is the side opposite.

TABLE OF LAND MEASURE.

7.92 inches = 1 link.
25 links = 1 rod.
4 rods = 1 chain.
80 chains = 1 mile.

$$\left.\begin{array}{l}10 \text{ square chains}\\ 160 \text{ square rods}\\ 43560 \text{ square feet}\end{array}\right\} = 1 \text{ acre.}$$

EQUIVALENTS.

Laterals 4 rods apart are at the rate of 40 rods to the acre.
One acre-inch in 24 hours equals .042 second-feet.
A miner's inch equals .025 second-feet.
One mile an hour equals 1.47 feet a second.
One second-foot equals 450 gallons a minute.

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